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SOME OBSERVATIONS ON THE QUALITIES OF PAVING BRICKS.

BY

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SOME OBSERVATIONS ON THE QUALITIES OF PAVING BRICKS.

By EDWARD ORTON, JR., Columbus, Ohio.

In the autumn of 1909, the National Paving Brick Manufacturers' Association[1] caused an investigation of the rattler test as applied to paving bricks to be made, with intent to discover the causes of the wide discrepancies found between the results obtained by different engineers and brick testers. The rattler test, as set forth in specifications by the National Brick Manufacturers' Association in 1901, had been in use 8 years or more without any substantial alteration, but at no time since the adoption of the test had it been usual to find close concordance between different laboratories when testing the same material, and these differences in some cases were so great as to impair the confidence of both manufacturers and consumers in the value of the test. The convenience of the rattler test, its already wide adoption, its demand for the same qualities which are demanded by street wear, all united to make its retention of importance.

The failure to check was attributable to the laxity of the original specifications, which permitted the use of variously designed machines, differing even in details of construction in the revolving barrel itself, as well as giving too wide discretion in the matter of speed of rotation, renewals, physical properties of shots, constitution of charge, weighing of fragments, etc. The new effort was to be directed to the removal of this laxity, and to so tie down the operators that if they followed the rules of the test, they could not vary in result, except in so far as the material itself varies.

In February, 1910, the writer, learning of this investigation, proposed to the officers of this Association to cooperate with them in carrying the study through. The idea advanced was to make all studies in duplicate, in two

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[1] Not to be confused with the National Brick Manufacturers' Association, which is an entirely different body.

different laboratories, and then, by exchange of data, find and eliminate the causes of variation. This proposal involved the entire independence of each laboratory, each to pay its own costs, except that the machine for making the tests, and the samples to be tested, should be furnished by the Association. This proposal was accepted and a long and costly investigation made. Mr. Marion W. Blair was appointed by the Association to take charge of their portion of the work and continued in charge to the end. The writer desires at this point to acknowledge his indebtedness to Mr. Blair for many suggestions during the course of the work.

In planning the investigation to be made, the primary object was to define the rattler test as a test, and eliminate its causes of variation, but a secondary object entered in, *viz.*, to study paving bricks as such, and learn what degree of variability to expect in the material and from what causes it comes. The results of the first part of the study, with improved specifications for the rattler test, have been transmitted to another organization.[1]

The results of the second part are presented herewith. In preparing this second study, the writer has used the data obtained from his own laboratory only. An equal amount of work was done by Mr. Blair in his laboratory, and this data could have been included in this study had it been deemed desirable. To have done so would have doubled the mass of data without altering the conclusions here reached.

LINES OF STUDY UNDERTAKEN.

The following lines of study were taken up:

First, what differences in mean rattling strength should be expected in first-class paving bricks due to the position of the sample in the kiln?

Second, in first-class paving bricks of the same make,

[1] American Society for Testing Materials, Vol. XI. Joint paper by Marion W. Blair and Edward Orton, Jr.

and which have had the same burning treatment, what variation in rattling strength should be expected from structural differences and concealed defects?

Third, among different brands of paving bricks having a reputation for good quality and which have been in use for 10 years or more in the streets of many cities, what variation may be expected in their ability to withstand the rattler test?

NATURE AND RESULTS OF THE EXPERIMENTS PERFORMED.

Four samples, designated successively Series A, E, F and G, consisting of 2100 bricks each, were selected by Mr. Blair. In each case these were taken from one kiln at the factory where made, and seven hundred of each sample were chosen to represent the upper third of the kiln, seven hundred to represent the middle third and the remaining seven hundred the lower third of the kiln. These respective portions were taken from a compact block or area of apparently uniform hardness and the samples were chosen to represent the best material in their respective levels of the kiln.

Each large sample was then marked, loaded into a car and shipped at full car rates, to avoid danger of mixing in handling. One-half of each lot of each bench was taken at one laboratory and the balance went to the other. Each laboratory, therefore, received 350 bricks from each bench of each sample, or 1050 in all.

On receipt of these samples, they were housed, or placed in roofed piles, to prevent their becoming or remaining more than "air damp." From each lot of 350 bricks, 100 were taken at random, dried in a kiln 24 hours at a temperature not exceeding 200° C. nor less than 100° C., cooled, marked with numbers in white paint, weighed to the nearest one-hundredth of a pound, soaked in water for 48 hours, wiped and reweighed, the difference taken and per cent. absorbed calculated. The wet bricks were then dried out in the kiln as before, for 24 hours.

The absorption per cents. were then arranged in column form, in order of numerical value. The ten highest were grouped together, and the ten lowest. The remaining eighty were then grouped in eight groups, so selected that every charge contained an assortment of bricks of which the average was within one or two hundredths per cent. of every other charge. Two sample charges are shown herewith, to illustrate.

Table I.

Absorption Per Cents.

No. of brick	Charge 1.	Charge 2
1	0.33	0.32
2	0.42	0.42
3	0.59	0.52
4	0.62	0.62
5	0.82	0.83
6	0.92	0.92
7	1.00	1.04
8	1.12	1.18
9	1.43	1.43
10	1.62	1.43
Average	0.88	0.87

These eight charges were then divided into two lots of four each, to each of which one of the two extra charges was given. One lot contained 4 average charges and the charge of highest absorption out of the one hundred bricks under classification, and the other lot contained four average charges and the charge of lowest absorption. One lot was given the rattler test with cubic shot and the other with spherical shot.

From the remaining 250 bricks of each lot, 100 more were taken and divided up into 10 charges at random. These 10 charges were then rattled, 5 with the cubic shot and 5 with spherical shot.

From the remaining 150 bricks, 75 more were taken and divided into 5 charges of 15 each, and these were

rattled with no shot at all. The remaining 75 bricks were held back for extras, if needed.

The rattler tests were thus made with cubic shot, spherical shot, and no shot, upon ungraded bricks, and with cubic shot and spherical shot upon bricks graded by the absorption test. This was done for all three benches of each kiln. The following scheme shows more clearly the plan of work:

Table II.

			No. of charges	No. of bricks per charge	Total No of bricks for each set of tests
Top zone	Cubic shot	Air-dry, ungraded	5	10	50
		Graded by absorption	5	10	50
	Spherical shot	Air-dry, ungraded	5	10	50
		Graded by absorption	5	10	50
	Without shot	Ungraded by absorption	5	15	75
Middle zone	Cubic shot	Air-dry, ungraded	5	10	50
		Graded by absorption	5	10	50
	Spherical shot	Air-dry, ungraded	5	10	50
		Graded by absorption	5	10	50
	Without shot	Ungraded by absorption	5	15	75
Lower zone	Cubic shot	Air-dry, ungraded	5	10	50
		Graded by absorption	5	10	50
	Spherical shot	Air-dry, ungraded	5	10	50
		Graded by absorption	5	10	50
	Without shot	Ungraded by absorption	5	15	75
Totals			75		825
Reserve supply of bricks to each investigator for his own use and for checking					225
Total bricks required per sample for each laboratory					1050

The rattler tests were the standard test of the N. B. M. A. in the case of the cubic shot, and in the spherical shot tests, the only intentional variation was in the substitution of $1\frac{7}{8}$-inch spheres for the $1\frac{1}{2}$-inch cubes, and $3\frac{3}{4}$-inch spheres for the $2\frac{1}{2} \times 2\frac{1}{2} \times 4\frac{1}{2}$ parallelograms. In each class, the weights of the small-sized and large-sized shots were the same. All the other conditions of each test were kept as nearly identical as possible. In part of Series A and E, a new variety of stave was tried as noted in the foot-notes. In Series C, also a new set of staves of the original type was used:

Table III. Series A.

Lower Bench.

	Charges graded by absorption				Charges ungraded by absorption		
	Cubic shot	Absorption, per cent.	Spherical shot	Absorption, per cent.	Cubic[1] shot	Spherical[1] shot	No shot
	18.57	1.24	20.64	1.25	20.86	22.58	26.21
	18.84	1.25	20.19	1.22	22.05	23.23	25.23
	18.18	1.25	21.26	1.25	18.86	24.14	25.32
	16.87	1.24	20.08	1.24	20.18	24.06	22.98
	17.92	0.58	22.69	3.39	21.84	23.68	25.85
Av.	18.07		20.97		20.76	23.54	25.12
			Middle Bench.				
	17.76	1.01	17.96	1.03	18.08	22.05	24.84
	16.15	1.01	18.03	1.00	18.74	22.52	22.32
	15.93	1.01	19.15	0.99	19.30	23.28	21.58
	15.24	1.01	17.22	1.01	18.30	21.01	23.07
	18.71	1.66	18.25	0.58	20.42	20.92	24.44
Av.	16.65		18.12		18.97	21.95	23.25
			Upper bench.				
	17.89	1.75	17.74	1.75	20.48	23.41	22.27
	16.20	1.75	19.12	1.75	18.36	22.84	21.88
	18.41	1.75	19.28	1.75	21.53	22.28	23.55
	18.14	1.75	19.25	1.75	19.47	25.17	23.02
	20.68	3.01	17.03	0.91	20.12	23.33	22.61
Av.	18.28		18.48		19.99	23.40	22.65

[1] The 15 tests in these columns were made with the old form of channel steel staves, in badly distorted condition from warpage. The other tests of this series were made with a lined channel steel stave in good condition. Comparisons cannot be drawn between different columns, and only between the different tests of one column at a time.

Table IV. Series E.

	Charges graded by absorption				Charges ungraded by absorption		
	Cubic shot	Absorption, per cent.	Spherical shot	Absorption, per cent.	Cubic[1] shot	Spherical[1] shot	No shot
Lower bench.							
	18.42	2.91	20.19	2.91	19.54	24.63	25.80
	18.73	2.92	20.87	2.91	20.43	22.53	26.14
	17.80	2.92	20.33	2.91	19.19	24.44	26.66
	18.59	2.91	20.15	2.91	21.97	22.97	24.78
	16.55	0.96	22.70	4.41	19.62	23.24	25.22
Av.	18.01		20.85		20.15	23.56	25.72
Middle Bench.							
	15.36	1.22	18.81	1.23	18.31	19.18	23.11
	15.49	1.20	19.31	1.23	18.43	22.16	22.74
	15.98	1.21	18.52	1.21	17.03	21.58	23.51
	17.36	1.21	18.96	1.21	19.64	21.34	23.27
	18.88	3.24	16.84	0.55	18.57	20.97	23.14
Av.	16.61		18.49		18.34	21.06	23.15
Upper Bench.							
	16.78	0.94	17.54	0.94	15.72	16.86	21.42
	16.74	0.94	17.72	0.94	16.79	18.59	20.96
	15.33	0.94	17.34	0.94	14.41	17.85	21.46
	16.32	0.94	17.58	0.94	16.24	17.88	22.65
	17.45	1.84	16.11	0.55	16.31	17.64	19.83
Av.	16.57		17.26		15.85	17.76	21.26

[1] The 10 tests represented by the Lower and Middle benches of these columns were made with the old form of channel steel staves, in badly distorted condition from warpage. The other tests, representing the Upper bench in the columns, and the other three columns complete, were made with a lined channel steel stave in good condition. Comparisons can only be drawn between the different tests in one column, and in this instance not quite a complete column is comparable.

Table V. Series F.

Lower Bench.

	Charges graded by absorption				Charges ungraded by absorption		
	Cubic shot	Absorption, per cent.	Spherical shot	Absorption, per cent.	Cubic shot	Spherical shot	No shot
	14.67	1.35	17.74	1.38	15.82	21.46	22.19
	16.27	1.37	19.30	1.39	16.38	20.58	22.46
	16.75	1.39	19.20	1.40	15.29	20.18	22.77
	17.72	1.39	20.63	1.36	16.36	22.22	22.73
	18.80	0.67	19.21	1.88	18.77	18.87	23.26
Av.	16.84		19.21		16.52	20.66	22.68

Middle Bench.

	14.88	0.82	19.18	0.82	16.61	19.73	21.62
	16.24	0.81	17.81	0.81	16.58	20.08	21.93
	16.50	0.82	19.02	0.84	16.94	19.60	19.80
	15.36	0.82	18.70	0.82	15.83	19.00	19.00
	14.61	0.30	20.75	1.44	17.50	20.81	20.23
Av.	15.52		19.09		16.69	19.84	20.51

Upper Bench.

	18.90	0.88	22.04	0.88	18.16	20.00	23.55
	16.86	0.87	23.75	0.92	18.59	20.80	25.23
	17.65	0.93	19.69	0.89	20.40	22.55	24.61
	18.59	0.91	20.28	0.89	19.88	20.20	22.49
	19.51	1.86	18.28	0.26	16.66	21.71	25.11
Av.	18.30		20.81		18.74	21.05	24.19

Table VI. Series G.

	Charges graded by absorption per cent.				Charges ungraded by absorption		
	Cubic shot	Absorption per cent.	Spherical shot	Absorption per cent.	Cubic shot	Spherical shot	No shot
Lower Bench.							
	15.63	1.00	19.82	1.00	16.81	19.91	23.93
	16.27	0.98	19.30	1.01	17.23	19.06	22.61
	16.92	0.98	21.12	1.01	17.08	19.08	21.88
	16.83	0.98	19.67	1.02	17.34	21.02	22.36
	16.35	1.40	21.69	0.36	19.44	20.05	22.93
Av.	16.40		20.32		17.58	19.82	22.74
Middle Bench.							
	17.35	1.16	20.72	1.14	16.60	19.71	22.05
	17.87	1.15	21.25	1.14	17.47	23.13	23.96
	17.96	1.14	21.85	1.16	18.83	21.19	25.04
	17.78	1.15	20.39	1.15	17.65	20.76	23.12
	17.96	0.49	29.70	2.48	18.56	22.05	24.13
Av.	17.78		22.78		17.82	21.36	23.69
Upper Bench.							
	18.87	1.56	22.06	1.58	16.74	22.02	24.19
	18.76	1.57	21.49	1.58	17.43	22.10	24.36
	17.29	1.55	21.51	1.56	17.55	22.55	24.45
	17.64	1.55	21.20	1.58	16.72	22.60	24.42
	20.77	2.42	21.60	0.94	17.25	22.31	24.23
Av.	18.66		21.57		17.14	22.31	24.33

In addition to the above four series, another sample, designated Series C, selected exactly as before, was tested in like manner, except that the grading of the 100 bricks by absorption was abandoned, and a new set of staves was used, of the same variety as used in the four preceding series.

Table VII. Series C.

Lower Bench.

	Cubic shot	Spherical shot	No shot
	22.96	22.53	26.17
	21.84	23.23	27.73
	21.94	22.86	27.12
	20.74	21.14	27.57
	22.90	22.36	27.76
	21.46	22.60	
	21.87	23.81	
	20.40	21.86	
	21.51	23.73	
	21.52	23.58	
Average,	21.71	22.76	27.27
		Middle Bench.	
	22.13	24.76	26.66
	24.34	22.69	28.91
	23.11	23.18	26.29
	23.37	22.42	28.46
	23.00	24.18	26.91
	21.01	20.71	
	23.81	23.54	
	24.62	21.94	
	26.11	22.69	
	24.93	21.75	
Average,	23.67	22.79	27.45
		Upper Bench.	
	22.92	21.59	25.75
	21.03	22.12	25.77
	23.78	21.71	26.09
	21.15	22.67	25.72
	21.62	22.31	
	22.35	22.25	
	20.72	23.10	
Average,	21.93	22.25	25.74

Series D. Series D was taken from a loaded car and did not represent grading as to level in the kiln. It merely represented the rejection of seconds and culls, according to the usual visual standards. In place of 2100,

3000 were taken, giving each operator 1500. These were used without grading by absorption in a series of tests at 10 brick per charge. One point to be determined in these series was the influence of the composition of the iron in the shots. Shots of the spherical shape only were used in making this comparison. Another point upon which evidence was sought was the influence of various types of staves, and in these tests, the shots were kept uniform in quality and shape and the staves were the only variable. Altogether, in this series, 130 charges were tested by each operator using 1300 bricks each. Tables VIII and IX give these data:

Table VIII.

Using shot No. 1	Using shot No. 2	Using shot No. 3	Using shot No. 4	Using shot No. 5
21.06	20.25	21.78	24.25	21.47
23.06	21.50	22.71	23.24	21.70
20.96	22.05	21.47	21.78	22.58
24.31	19.24	22.36	23.20	21.94
23.63	22.96	21.31	24.40	24.43
24.60	22.06	21.91	23.44	21.47
23.37	21.08	20.95	24.29	24.00
22.58	21.49	21.88	24.72	21.80
26.41	22.18	20.79	22.12	22.61
23.63	21.98	19.57	24.60	24.07
Average, 23.37	21.47	21.47	23.60	22.60

Table IX.

Using stave No. 1	Using stave No. 2	Using stave No. 3	Using stave No. 4	Using stave No. 5	Using stave No. 6	Using stave No. 7
21.06	21.40	20.49	20.45	20.37	19.39	20.61
23.06	22.28	22.35	21.72	21.23	19.43	20.13
20.96	21.21	22.13	22.61	20.78	19.47	21.93
24.31	21.57	22.02	22.47	21.81	20.64	21.55
23.63	22.61	22.87	25.12	23.44	21.13	20.43
24.60	23.87	22.22	20.49	20.21	21.41	20.00
23.37	22.05	20.86	22.06	21.15	17.69	20.05
22.58	23.01	21.54	25.12	20.97	21.24	21.25
26.41	25.64	22.16	22.48	20.55	19.65	20.84
23.63	23.30	23.08	22.43	20.76	19.62	19.73
Average, 23.37	22.59	21.97	22.49	21.12	19.96	20.65

Tentative Standard Series. At the conclusion of these tests, a tentative standard process was formulated, using the information which had been gained as to types of shot and types of staves, and 10 brands of bricks, with 10 charges of each brand, were now run by the proposed process.

The samples used in these 10 comparisons were in part what was left of the Series A, C, E, F and G, together with five new lots, designated as F2, H, K, M and P, respectively. These lots were mostly selected by the manufacturers and represented what they thought was their best material, but it does not represent any special bench in a kiln, nor was it necessarily chosen from any single kiln. Lot F2 was selected from a street delivery. Tables X and XI give these data:

Table X.

Tests Made by the Revised or Tentative Standard Rattler Process.

	Series A	Series C	Series E	Series F	Series F2
	18.78	23.80	18.55	17.51	17.25
	20.06	24.44	18.23	18.44	16.94
	20.24	23.95	20.09	18.75	19.27
	18.72	24.97	18.08	18.63	17.55
	19.47	24.49	19.02	17.99	18.92
	19.26		18.83	17.30	16.65
	18.96		19.60	17.48	15.86
	19.89		20.54	19.51	15.44
	20.38		20.87	18.70	15.65
	20.12		19.37	17.74	18.46
Average,	19.59	24.33	19.31	18.20	17.19

Table XI.

	Series G	Series H	Series K	Series M	Series P
	19.14	25.67	20.30	18.41	16.40
	17.90	30.47	18.42	18.08	16.46
	18.45	30.23	17.68	20.36	16.81
	18.24	25.66	19.42	18.40	17.40
	18.60	29.76	18.97	18.78	16.84
	19.58	23.33	17.59	19.64	
	18.53	25.07	20.23	17.24	
	19.35	28.34	18.57	19.25	
	19.13	29.44	18.46	18.38	
	18.81	30.25	19.63	20.20	
Average,	18.77	27.82	18.92	19.07	16.78

The foregoing tables, containing the results of 585 tests, represent that part of the data produced by the writer in the joint investigation. As explained previously, Mr. Blair's portion is not used in this study.

It will also be understood that comparisons between the different kinds of shots, or between different lots of the same shots, or between the different kinds of staves, cannot safely be made in the foregoing, because the conditions governing that portion of the work have not been set forth here. The conditions in any one vertical column of figures are consistent and comparable, except where indicated otherwise, but from column to column, they are not always so. Hence, the only conclusions which should here be drawn are those based on a study of the uniformity of the material, as disclosed by the different sorts of tests applied.

I. INFLUENCE OF POSITION IN THE KILN.

The popular conception of engineers and brick users, and possibly some brick manufacturers also, is that any single brand of paving brick has a characteristic quality inherently its own, and that when a bid to supply paving bricks is made by a brickmaker, and a sample is filed and tested, and a contract is let upon that bid, the brickmaker

should deliver material which, on test, will show the same figures as the sample submitted. In many cases great injustice has been done to brickmakers by a too literal application of this conception by engineers, directors of public improvements and similar officials.

The general idea outlined above has a foundation of truth. A paving brick clay *does* tend to produce a characteristic product. The product of one clay *is* inherently better or worse than another. Some clays produce brittle, dense, glassy products; others soft, punky products; others hard, stony, tough products; and so on, with innumerable gradations between these types. But the fact to to be borne in mind in this connection is that these inherent or characteristic qualities are much disguised or concealed by two sets of factors—variation in burring treatment, which may or may not have been the best, and variation in structure due to the flow, under pressure, of clay through the die of the brick machine.

In any given clay, the temperature range over which its qualities remain at their best, or close to it, is of the utmost importance. In some few clays this range in heat treatment is quite wide, and but little difference in quality is found from top to bottom of a kiln. In many more, this heat range is rather close, and either a little over or under the best point will show at once on the product and any wide departure will discredit the material at once. In some other clays, the available heat range is so very narrow that the material cannot be worked for vitrified goods profitably at all.

It is of course well recognized that in any kiln there may be zones or areas in which the distribution of the heat is not good, and the product may be either over- or underfired in consequence. The question upon which light is here being sought is to what extent does the quality of paving material vary in kilns that are *well burned*, and which manufacturers would put forward as good? It is not to find out how much un-uniformity one may find in a kiln of paving bricks, by hunting out the hot spots and

cold spots, but rather how much uniformity may one find under good working conditions?

With this in view, the data presented in Series A, E, F, G and C were analyzed with care. The remaining data gave no evidence on this point.

Table XII.
Averages of Each Series by Benches.
Series A.

Bench of kiln	Graded charges[1]				Ungraded charges[2]		
	Cubic shot		Spherical shot		Cubic shot	Spherical shot	No shot
	Rattler	Absorption	Rattler	Absorption			
Lower	18.11	1.24	20.56	1.24	20.76	23.54	25.12
Middle....	16.27	1.01	18.09	1.01	18.97	21.95	23.25
Upper	17.66	1.75	18.85	1.75	19.99	23.40	22.65

This brick was fired in kilns of the down-draft type. The center of the kiln yields consistently the better ware in four out of five comparisons. This indicates that the upper ware was slightly over-fired, for its absorption per cents. are higher as well as its rattler losses, such as would ensue from a slightly spongy structure. The lower ware is probably higher in rattler losses from a slightly less complete vitrification, as indicated by its slightly higher absorption per cent., though the difference is seemingly trifling. In the case of the no shot charge, the upper bench yields a little better figures than the middle. This may be due to the superior activity of an iron shot charge over brick-on-brick in attacking a spongy exterior structure caused by over-fire, or it may be an accidental figure, caused by one erratic result in an average of only five tests.

[1] Average of 4 tests only. The charges representing the 10 highest and 10 lowest absorptions in 100 bricks were discarded in this comparison.

[2] Average of 5 tests each. Their average absorption cannot possibly vary by more than very small amounts from the averages given in the graded series.

Table XIII.
Series E.

Bench of kiln	Graded charges[1]				Ungraded charges[2]		
	Cubic shot		Spherical shot		Cubic shot	Spherical shot	No shot
	Rattler	Absorption	Rattler	Absorption			
Lower	18.38	2.92	20.38	2.91	20.15	23.56	25.72
Middle....	16.05	1.21	18.90	1.22	18.34	21.06	23.15
Upper	16.29	0.94	17.54	0.94	15.85[3]	17.76[3]	21.26

This ware was fired in down-draft kilns. It is apparently not over-fired in the upper zone of the kiln, for its absorption per cent. and rattling strength both indicate a slight superiority over the middle, and a decided superiority over the bottom benches. These relations hold in four out of the five comparisons and in the fifth the differences are so small as to be of little significance.

Table XIV.
Series F.

Bench of kiln	Graded charges[4]				Ungraded charges[5]		
	Cubic shot		Spherical shot		Cubic shot	Spherical shot	No shot
	Rattler	Absorption	Rattler	Absorption			
Lower	16.35	1.38	19.22	1.38	16.52	20.66	22.68
Middle....	15.74	0.82	18.68	0.82	16.69	19.84	20.51
Upper	18.00	0.89	21.44	0.89	18.74	21.05	24.19

[1] Averages of 4 tests only. The two charges representing the 10 highest and 10 lowest absorption figures were discarded.

[2] Averages of 5 tests each.

[3] Made with different staves than the two other benches. This magnified the difference somewhat.

[4] Averages of 4 tests only. The two charges representing the 10 highest and 10 lowest absorption figures were discarded.

[5] Averages of 5 tests each.

In four out of five comparisons, the middle of the kiln yields the best material. In one comparison, the lower bench surpasses the middle by a few hundredths. This material is fired in down-draft kilns and the clay requires a high temperature to bring it to vitrification. Forcing the fires, in order to get the bottom hard enough, results in damage to the upper portion, as is very clearly shown above. The damage, however, is not by production of spongy structure to any serious extent, but comes about from brittleness chiefly.

Table XV.
Series G.

Bench of kiln	Graded charges[1]				Ungraded charges[2]		
	Cubic shot		Spherical shot		Cubic shot	Spherical shot	No shot
	Rattler	Absorption	Rattler	Absorption			
Lower....	16.41	0.98	19.98	1.01	17.58	19.82	22.74
Middle....	17.74	1.15	21.05	1.15	17.82	21.36	23.69
Upper....	18.14	1.56	21.56	1.57	17.14	22.31	24.33

The ware represented in these tests was fired in a kiln of horizontal draft. The fire holes deliver their heated gases near the floor, and this is illustrated nicely in four out of the five comparisons here made. The top ware in this kiln is the softest ware.

Table XVI.
Series C.

Bench of kiln	Cubic shot	Spherical shot	No shot
	10 charges	10 charges	5 charges
Lower...........	21.71	22.76	27.27
Middle..........	23.67	22.79	27.45
Upper...........	21.93	22.25	25.74

[1] Averages of 4 tests only. The two charges representing the 10 highest and 10 lowest absorption figures were discarded.

[2] Averages of 5 tests.

No absorption tests were made upon this material. It was burned in down-draft kilns, but did not attain as high a degree of vitrification as most of the preceding samples did. Its top portion is a little better than the middle and lower benches in all three comparisons, only one discordant figure being noted and that for a few hundredths. While the rattling strength of this material is poorer than the preceding, its uniformity from bench to bench is very excellent indeed, and not surpassed by any brand tested.

Summary of Section I.—Judging from these five brands of bricks, representing five factories in different parts of the country, each a successful and prominent one in its district, and representing different varieties of clays and different types of kilns, it is possible for paving brick makers to keep their product within an average fluctuation of 2 to 3 per cents. rattler loss, so far as differences in burning are concerned. Care must be taken that this statement is thoroughly understood. It applies to *averages* only. The fluctuation of bricks in any one zone may greatly exceed this amount, as will be shown in the next section. In considering any small amount of data, the fluctuations of the individual charges are so great as to completely obscure the above relationship. But where averages of 5 or 6 tests of one bench can be compared against an equal quantity from another, the above principle seems to hold quite closely.

It is not believed that the average performance of the average paving brick plant would show as small a fluctuation in its output as two or three per cent. due to variations in their burning treatment, but the instances studied show what is being done among some of the better plants.

II. VARIATION OF BRICKS OF THE SAME HARDNESS, DUE TO STRUCTURAL DEFECTS.

In a bar of clay expressed from a brick machine, a considerable length, say 50 or 100 feet, will probably show all the important peculiarities of bar structure which can occur, at least those due to occur at any single temper of

the clay. A very soft or extra hard temper might still further vary the character of the output. But if one takes one short length of a clay bar, representing one brick, and compares it with another, cut from a point a little further along in the same bar, the variation between the two may be considerable. One may possess laminations, dry spots, cavities, air blisters, surface cracks, etc., which the other does not show. In fact, no two seem exactly alike.

It follows from this, that in any charge of ten bricks chosen for a rattler test, there is an assortment of somewhat dissimilar units, and this dissimilarity is liable to cause the results to fluctuate rather widely, even when the burning treatment has been all that could be desired.

With a view to finding out what variation in strength, as measured by loss in rattling, good paving bricks of uniform hardness show, the following data have been analyzed out of the tables given in Tables III to XI, inclusive:

The *Range* is obtained by subtracting the minimum result from the maximum of the set. The *Deviation* is obtained by first calculating the mean of the set and then determining the differences between each observation and the mean. The sign of these differences (*i. e.*, whether plus or minus) is ignored. The differences obtained are then averaged, and the figures thus obtained show in the given set of results how much any individual result is likely to deviate from the general average or mean. This term is not necessarily in close agreement with the ange between maximum and minimum, for *one* erratic result may make the latter quite wide, but not greatly affect the average deviation from the mean.

Tables XVII–XXIV give the results of this study:

Table XVII.
Series A.

Bench in kiln	Cubic shot		Spherical shot		No shot	
	Total ranges	Average deviations	Total ranges	Average deviations	Total ranges	Average deviations
Lower	1.97	0.55	2.61	0.80	3.23	0.83
	3.19	0.99	1.56	0.51		
Middle.....	3.47	1.16	1.93	0.46	3.26	1.11
	2.34	0.71	2.36	0.79		
Upper	4.48	1.02	2.25	0.88	1.67	0.49
	3.17	0.86	2.89	0.71		
Average ...			2.26	0.69		

Table XVIII.
Series C.

Bench in kiln	Cubic shot		Spherical shot		No shot	
	Total ranges	Average deviations	Total ranges	Average deviations	Total ranges	Average deviations
Lower	2.09	0.54	2.22	0.68	1.59	0.50
	1.95	0.71	1.47	0.38		
Middle.....	2.21	0.40	2.34	0.82	1.62	0.99
	5.10	1.35	2.83	0.79		
Upper	1.08	0.34	2.75	1.00	0.55	0.15
Average ...			2.32	0.73		

Table XIX.
Series E.

Bench in kiln	Cubic shot		Spherical shot		No shot	
	Total ranges	Average deviations	Total ranges	Average deviations	Total ranges	Average deviations
Lower	2.18	0.68	2.55	0.75	1.88	0.57
	2.78	0.82	2.10	0.77		
Middle.....	3.52	1.20	2.47	0.66	0.77	0.19
	2.61	0.58	2.98	0.77		
Upper	2.12	0.56	1.61	0.46	2.82	0.69
	2.38	0.71	1.73	0.41		
Average ...			2.24	0.64		

Table XX.
Series F.

Bench in kiln	Cubic shot		Spherical shot		No shot	
	Total ranges	Average deviations	Total ranges	Average deviations	Total ranges	Average deviations
Lower	4.13	1.13	2.89	0.59	1.07	0.28
	3.48	0.69	3.35	0.96		
Middle.....	1.89	0.68	2.94	0.69	2.93	1.00
	1.67	0.42	1.81	0.48		
Upper	2.65	0.84	4.47	1.45	2.74	0.96
	3.74	1.12	2.55	0.86		
Average....			3.00	0.84		

Table XXI.
Series G.

Bench in kiln	Cubic shot		Spherical shot		No shot	
	Total ranges	Average deviations	Total ranges	Average deviations	Total ranges	Average deviations
Lower	1.29	0.38	2.39	0.87	2.05	0.55
	2.63	0.74	1.96	0.60		
Middle.....	0.61	0.17	9.31[1]	2.56[1]	2.99	0.89
	2.23	0.69	3.42	0.97		
Upper	3.48	0.76	0.86	0.20	0.36	0.09
	0.83	0.32	0.58	0.21		
Average ...			3.09[1]	0.90[1]		

Table XXII.
Series D.

All tests with spherical shot. 10 tests per set.

	Shot No. 1	Shot No. 2	Shot No. 3	Shot No. 4	Shot No. 5
Total range..........	5.45	3.72	3.15	2.94	2.96
Average deviation from mean.........	1.15	0.77	0.65	0.84	0.93

[1] These figures are due to one very erratic result. Excluding this figure, on the presumption that there was something irregular about it, these values would be 1.46, 0.49, 1.78 and 0.55, respectively.

Table XXIII.
Series D.

	Stave No. 1	Stave No. 2	Stave No. 3	Stave No. 4	Stave No. 5	Stave No 6
Total range............	4.43	2.59	4.67	3.23	3.72	2.20
Average deviation from mean................	0.99	0.60	1.07	0.62	0.84	0.59
Grand average range in Series D.............						3.55
Grand average deviation form mean Series D.						0.82

Collecting terms from this bulky mass of data, we find:

Table XXIV.

Series	Grand average range between maximum and minimum in six sets of 5 tests each	Grand average deviation from mean, in sets of 5 tests each (Spherical shot tests only)
A............	2.26	0.69
C............	2.32	0.73
E............	2.24	0.64
F............	3.00	0.84
G............	3.09 (1.78)[1]	0.90 (0.55)[2]
D............	3.55[1]	0.82[1]

From the above, it can be seen that while in every large series of results, there are occasional ranges of 3.5, 4 and even 5 per cent. between maximum and minimum, the *ordinary or average range due to structural defects is between 2 and 3 per cent.*, and in a similar way, the ordinary departure of an individual test from the average of its set is about 3/4 of a per cent.

A well marked difference is observable between the first 5 series, composed of materials selected from the kilns with regard to uniformity of heat treatment, and Series D,

[1] Excluding one highly erratic result.

[2] Twelve sets of 10 tests each, instead of six sets of 5 each.

composed of a commercial shipment diverted from its purpose. The ranges in this series run up to over 5.46 per cent., and in no case fall below 2.20. This is in much closer accord with what is found constantly by engineers who carefully follow up brick deliveries on the street with rattler tests. Some of the material, and often much the largest part, is as good as the bidders' samples, but there is also generally some that is not as good—enough to give fluctuating and irregular tests, which destroy confidence in the test or in the material, according to the affiliation of the tester.

A similar study of the ranges and deviations of the results or the tentative standard comparisons does not disclose anything different, except that one material shows much higher figures. This material is soft and wears excessively in rattling, and as the tests show, is irregular and variable in addition and could not be considered as good or standard brand.

III. THE VARIATION IN ABILITY TO WITHSTAND THE RATTLER TEST DISCLOSED BY DIFFERENT BRANDS OF PAVING BRICKS OF GOOD REPUTATION.

In the foregoing tables (III to IX, inclusive), we have a large amount of data from six standard brands of paving bricks. Owing to variations in the conditions of the rattler test into which it is not necessary to go here, these data are not closely comparable, series to series, and must be set aside for the present purpose. In Tables X and XI we have the same series and four additional ones compared under strictly uniform conditions, in which every detail was most attentively watched. Although Series C and P are represented only by 5 tests each, owing to shortage of material, the other averages represent 10 tests apiece. These results have value for our present purpose. Marshaling the data here, we have:

Table XXV.

Series	Average of 10 tests	Maximum loss in 10 tests	Minimum loss in 10 tests	Range	Average deviation from mean
A	19.59	20.38	18.72	1.66	0.55
C	24.33[1]	24.97[1]	23.80[1]	1.17[1]	0.36[1]
D	21.47	22.71	19.56	3.16	0.65
E	19.31	20.87	18.08	2.79	0.77
F	18.20–[2]	19.51–[2]	17.30–[2]	2.21–[2]	0.51–[2]
	17.19–[3]	19.27–[3]	15.44–[3]	3.83–[3]	1.18–[3]
G	18.77	19.58	17.90	1.68	0.40
H	27.82	30.47	23.33	7.14	2.31
K	18.92	20.30	17.59	2.71	0.79
M	19.07	20.36	17.24	3.12	0.93
P	16.78[1]	17.40[1]	16.40[1]	1.00[1]	0.28[1]

A scrutiny of the above shows a remarkably satisfactory situation. Of the 10 brands, seven show below 20 per cent. average loss. The other three range in order 21.47, 24.33 and 27.82. In a study of the maxima, we also find that of the seven best materials, three do not reach 20 per cent. and 20.87 per cent. is the highest.

The relation between these figures, and the losses these same bricks would have shown under the old standard of the N. B. B. A. is problematical. The old test varied, as we now know, from a number of causes, chiefly the variable quality and condition of the shot, the lack of uniformity of the staves and heads of the barrels, the lack of uniformity in counting broken brick at the end of the test, the use of either 10 or 11 heavy shots to make up nearest to 75 lbs. of the shot charge, instead of always 10, and insufficiently close regulation of the speed. To compare results obtained in the past by that test is impossible, because we do not know exactly what the above variables were. Only approximations and estimates are now possible.

[1] On 5 tests only.

[2] Original sample, selected from the kiln.

[3] Second sample, chosen from street delivery.

It is the judgment of the writer that where the old test was done in a careful and skilful manner, with hard shot, stiff staves and closely regulated speed, the new test is distinctly easier than the old—probably by a per cent. Repeated tests demonstrate that the new test is about 2 per cent. easier than the old, if cubes and spheres of the same metal be used and the rattling chamber be the same in each test.

On the other hand, when the old test was executed with soft shot, or a springy, loose-jointed rattler, or with slow speeds (28+) the new test will be from 3 to 6 per cent. higher. It is probable that the average difference over the country as a whole between the new test accurately performed and the old test as it usually has been performed would be at least four per cent. and possibly five per cent higher.

From the preceding it appears, therefore, that the results in Table XXV could safely be marked down by 2 or 3 per cent. in translating into old-test terms. This would mean that seven out of ten of the blocks tested would pass an 18 per cent. standard easily, and 8 would pass at 20 per cent. Only two would have to be rejected.

Of course, it must be borne in mind that these tests generally represent picked material—picked either by Mr. Blair or by the manufacturer. In only one or two cases did the material represent commercial shipments. It is fair to suppose that commercial shipments would show a higher average loss, a higher range and a higher average deviation.

The showing made is good, nevertheless, and it should be useful to both engineers and manufacturers in all parts of the country to see, just at this time, what the brickmakers can do and what the new test will do.

CONCLUSIONS.

First. The variation in rattler test in well burnt charges of paving brick of one brand, due to position in the kiln, whether top, middle or bottom, has been kept down to between 2 and 3 per cent. in the case of five representative products studied. It would seem that there is no real need of its being allowed to exceed that in well-equipped plants using suitable clays.

Second. The variation in rattler test in uniformly burnt charges of paving bricks of one brand, due to structural causes, is found to run between 2 and 3 per cent. Occasional erratic tests may increase the range to 4 or 5 per cent. This conclusion is drawn from the study of ten brands.

Third. From the foregoing, it follows that in dealing with paving bricks of first-class quality, we must expect a variation of from 3 to 5 per cent. in the output, as measured by rattler losses. In plants where the output is not of first-class quality, due to manufacturing causes, or burning irregularities or unsuitable clay, this margin is likely to be much wider—probably 5 to 8 per cent. in second-quality material and more than that in bad cases.

Fourth. To attempt to judge of the quality of a paving brick by the rattling of a single charge of 10 bricks is entirely improper. With material which, under good conditions, shows an inherent variability within the limits shown above, not less than the average of 5, or better, 10 tests should be insisted upon before ruling out a paving brick because of failure to meet its guarantee or the specified limits.

Fifth. Engineers, in setting the limits of losses in paving bricks tested for any purpose, should invariably insert the word *average* in their specifications. For instance, a properly written clause might say: "When so tested (referring to the method of conducting the test) the *average* loss on rattling 5 (or 10) consecutive charges, chosen as above provided, shall not exceed .... per cent."

Sixth. If for any reason an engineer is unwilling to abide by the *average* loss of 5 tests, or of all of the tests (exceeding 5) made on the contract in question, and insists upon safeguarding himself by a provision setting a maximum loss above which no single charge may go without throwing out the entire lot of material, this maximum should certainly be very liberal, not less than 5 per cent. above the permissible average in any case.

The writer has here shown that in paving bricks of representative brands, among the best in the country, carefully selected by experts, or by their makers, there will still occur occasional erratic losses of 5 per cent. or more, and while these do not affect the average of large numbers of tests appreciably, they may so occur as to cause the rejection of an excellent material if a hard and fast maximum is insisted upon. In general, the writer believes that a maximum loss provision is not needed by engineers to secure excellent and reliable material, if they have wisely established the limit which the average must not exceed.

Seventh. On the question as to where the average rattler loss of a paving brick should be set to insure a good product, the writer believes that this question is one which should be settled for each locality by itself—it is affected by geographical conditions, freight rates, climatic conditions, traffic conditions in the locality, and by the kind of foundation and mode of laying the street. Obviously, no single standard would be wise or just. If it were made severe enough to be safe for all, it would cause the public to pay more for their streets than necessary in many places, and would put out of business many plants whose product is usefully employed, though not able to meet the drastic specification for important streets in large cities.

Eighth. It has not yet been proven by actual research, so far as the writer is informed, just what the maximum limits of rattler loss may be for a paving brick to make a good street, under normal city conditions on the 40th parallel. Certainly, many bricks which have not been

able to pass good rattler tests, when well laid, have made excellent streets. Until this relationship between rattler loss and street wear is in some degree established, city engineers should not raise the requirements under the new test higher than at least the average paving brick plant can meet. There exists good ground for the opinion that a mediocre or poor brick, if excellently laid in the street, may surpass the performance of the best bricks, poorly laid. If this should prove to be true, it will not mean the abandonment of the rattler test—it will merely mean a shifting of the limits of acceptance of its verdict.

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THE COEFFICIENT OF EXPANSION AND CONTRACTION OF WHITE WARE BODY MIXTURES

BY

ROSS C. PURDY AND AMOS P. POTTS.

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INFLUENCE OF CLAY, FELDSPAR AND FLINT ON COEFFICIENT OF EXPANSION OF CERTAIN WHITE WARE MIXTURES. BISCUITED AT CONE 10.

By Ross C. Purdy and Amos P. Potts.[1]

REVIEW OF PUBLISHED WORK OF OTHERS.

A most searching review of the literature on physics, physical chemistry, ceramics and allied subjects, shows that there is a conspicuous lack of data on this subject. It is true that a number of determinations of the coefficients of expansion of certain porcelains have been made, but in these cases no attention was paid to composition or constitution.

(1) T. G. Bedford read a paper on "The Expansion of Porcelain with Rise of Temperature" before Section A, of the British Association for the Advancement of Science, at Dover, in 1899, in which he quotes Deville and Troost (*Phil. Mag.*, Vol. 49, p. 91) as having determined the cubical coefficient of a sample of Bayeux porcelain, used in the air thermometer, as being 0.000,016 to 0.000,017. This determination was made by the usual dilatometer method. He also quotes from an article by German investigators, Holborn and Wien (*Ann. der Physik und Chemie*, Vol. 47, p. 107), who measured a piece of Berlin porcelain (composition unknown) 9 cm. long, at room temperature, and again at 500° and 1000° C., and came to the conclusion that the expansion was constant at 0.000,004 per unit length at 0° C.

(2) Bedford, in the same paper, gives an account of a determination of his own. He used a tube of glazed Bayeux porcelain about 1 meter long and 1.7 cm. in external diameter. Two fine transverse scratches ran around the tube at a distance of about 91 cm. from each other. Using a standard length, and a pair of reading microscopes, he directly compared the distance between these marks at a series of temperatures, ranging from 0° C. to 830° C.

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[1] By permission of Dr. John A. Bownocker, Director Ohio Geological Survey.

The microscopes were supported on solid stone blocks, resting on a solid stone bench, and could be moved along their slides by means of micrometer screws.

The tube was heated in a gas furnace, supported on a stand provided with leveling screws by means of which the marks were kept in focus.

The distance between two diamond marks on a glass tube, kept in a trough of melting ice, was used as a standard length. This distance equaled 91.394 cm.

As a result of this investigation he obtained the following expression: The length at a given temperature equals the length at zero centigrade multiplied by $(1 + 34.25 \times 10^{-7}t + 10.7 \times 10^{-10}t^2)$ which shows that the expansion is not a constant, but that the curve expressing elongation with rise of temperature is of the form $(ax^2 + bx + 1)K = y$, rather than $(ax + 1)K = y$, as had been assumed by Deville and Troost, and also by Holborn and Wien.

(3) On March 14, 1902, Mr. A. E. Tutton read, before the Physical Society, a paper entitled "The Thermal Expansion of Porcelain," which is published in *Phil. Mag.*, 6th Series, Vol. 3, No. 18, June, 1902.

His determinations were made on pieces of the same tube which had been used by Bedford and also by Chappius. His method was to use the interference dilatometer which he had previously described in *Phil. Trans.*, A, Vol. 91, p. 313, and Vol. 92, p. 455. For each determination, he used a piece of the tube 12 mm. long, and he worked over a temperature range from 10° to 120°.

Tutton's formula is similar to that of Bedford's except that his constants differ. As determined by Tutton the formula is $Lt = L_0(1 + (2522t + 7.43t^2)10^{-9})$.

(4) The formula as determined by Chappius and quoted by Tutton (the present writers have been unable to find a published account of Chappius's work) is $L_t = L_0(1 + (2824.1t + 6.17t^2)10^{-9})$.

(5) Tutton also quotes an article by Holborn and Day (*Ann. der Phys. und Chem.*, Vol. 2, p. 505, 1900) in which

they state that between 250°–625° C. the formula for Berlin porcelain should be

$$L_t = L_0(1 + (2954t + 1.125t^2)10^{-9}).$$

(6) Mr. Watts, of the American Ceramic Society, published, in the *Trans. A. C. S.*, a paper on the coefficient of expansion as determined by him on a piece of porcelain of the type used in the manufacture of electric insulators at Victor, N. Y. His result, calculated by the straight line formula, gives as the coefficient of linear expansion for this particular porcelain 0.000,005,357.

(7) Dr. Mellor, in Vol. 5, *English Cer. Soc. Trans.*, describes a measurement of the coefficient of expansion of some English floor tile bodies. He found their coefficient to be 0.000,007,7±.

These several investigators and their results are here tabulated for ease of comparison:

Investigators	Temperature range	Formula. Used and linear coef. obtained	Cubical
Mellor	15°–100°	$Lt = L_0 (1 + at) : a = 0.000,007,7$	
Deville and Troost	Not given	$Lt = L_0 (1 + at) : a = 0.0000055$	0.000016 to 17
Watts	19°–243°	$Lt = L_0 (1 + at) : a = 0.0000054$	
Holborn and Wien	0°–1500°	$Lt = L_0 (1 + at) : a = 0.0000044$	
Bedford	0°– 830°	$Lt = L_0 (1 + (3425t + 1.07t^2)10^{-9})$	
Chappius	0°– 83°	$Lt = L_0 (1 + (2824t + 6.17t^2)10^{-9})$	
Holborn and Day	250°– 625°	$Lt = L_0(1 + (2954t + 1.125t^2)10^{-9})$	
Tutton	10°– 120°	$Lt = L_0 (1 + (2522t + 7.43t^2)10^{-9})$	

We have, then, the result of eight independent investigations, four of which were made on Bayeux porcelain, and three of these on portions of the same tube. Of the other four, two were upon Berlin porcelain, the third upon a porcelain of the American insulator type, and the fourth upon an English floor tile body.

Aside from these investigations we find:

(8) Le Chatelier, H. "Sur la dilatation du quartz," *Bull. Soc. Min. de France*, Vol. XIII, pp. 112–118,

Paris, 1890. (In connection with the expansion of clays upon burning.)

Coupeau, M. "Étude sur la dilatation des pâtes céramiques, III" *Bull. Soc. d'Encour.*, 97th year, Vol. III, 1274–1309 (Oct.), Paris, 1898.

(9) Vogt, Georges. "Observations deduites de l'étude sur les dilatations ceramiques de M. Coupeau," *Bull. Soc. d'Encour.*, 97th year, Vol. III, 1309–16 (Oct.), Paris, 1898.

(10) Granger, Albert. "Etude sur la dilatation des pâtes céramiques," *Moniteur scientifique*, Vol. LI, 385–392, Paris, 1899.

(11) Chantepie, M. "Sur la dilatation des pâtes céramiques," *Bull. Soc. d' Encour.*, 99th year, Vol. VI, 39–55, Paris, 1900. (Numerous diagrams and tables.)

Since the compositions of the porcelain used in these tests were not given, nor even available, they have but little bearing on the subject in hand.

VALUE OF SUCH DATA.

(1) The care which these investigators have exercised in their several methods to obtain accurate results has shown that they considered it very important to determine the coefficient of expansion of porcelain with a high degree of accuracy. In a majority of cases it was their intention to use the coefficient in the computation of temperatures by means of the air thermometer, for which purpose each was probably using a porcelain of the type examined. If it were of so great importance to know the coefficient of expansion of the particular type of porcelain which they were then using, of how much more importance is it to the manufacturer of scientific apparatus, if not to the scientist, to be able to appreciate the effect of variation in his body mix?

(2) But there is a second, and it would appear from a purely ceramic standpoint as a more important reason for the investigation of this matter, and that is the obtaining

of data bearing on the fundamental assumptions on which many of our theories are based.

In Vol. II, p. 572, of "Seger's Collected Writings," we find this statement: "The principal difficulties which arise in the production of a faultless union of body and glaze lie in the different expansions which these experience, when subjected to heat." From this assumption, Seger formulated a set of rules for controlling glaze fit. As a matter of fact, his rules are workable in some particular cases, but there is no proof of the validity of his fundamental assumptions. Furthermore, it has not been shown that his rules could be used in the manufacture of porcelain for scientific apparatus where low coefficient of expansion of the porcelain is a desideratum.

For a number of years, Mr. Stanley G. Burt investigated the effect of the body ingredients, particularly silica, upon glaze fit.[1] In the first two of these papers, he devotes most of his attention to flint—its origin, size of grain, etc., but in the last paper, he offers a series of what he calls "Coefficient Equivalents." He expressly states that these are arbitrary figures based upon his own experience. We will not, at this time, take issue with him as to the value of these figures for controlling glaze fit, but we raise a question concerning their value as *Coefficient of Expansion Equivalents*.

Is Seger's assumption correct? Is glaze fit a function of the relative coefficient of expansion of the body and glaze? As an aid in formulating working theories, an investigation of the fundamental assumptions is eminently worth the while.

THE PRESENT INVESTIGATION.

The bodies used are the same as those described by Ogden.[2]

Making the Trial Pieces.—The trial pieces for the

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[1] Trans. A. C. S., Vol. 3, p. 18; Vol. 5, p. 340; and Vol. 7, p. 133.

[2] Page 394, this volume.

expansion tests were pressed by hand into plaster moulds. In shape, they were rectangular, being 5″ long, 3/4″ wide, and 3/8″ thick.

Burning.—The trials were placed in saggars and fired with coke for 40 hours until cone 10 heat treatment was obtained. In placing the trials in the saggars, the expansion trials were laid lengthwise on a cushion of sand to prevent them from warping or bowing.

Description of Apparatus First Used.[1]—In the preliminary tests the following apparatus was used to determine the expansion of the trials.

Upon a triangular brass bar were mounted two microscope holders, which could be moved backward and forward along the bar under control of slow motion screws. In these holders were placed two microscopes each fitted with micrometers. In the microscopic field on each microscope were two horizontal parallel cross-hairs, one of which was stationary and the other controlled in movement by the micrometer wheel.

Heating of Trials.—It was decided to heat the trials by submerging them in an oil bath. For this purpose a bath tank was constructed of copper-tin, the tin being on the inside as it was less liable to the oxidation effects of the oil at high temperatures. The dimensions of the tank were 6″ in length, 3″ in width, and 2 1/2″ deep.

At first it was planned to heat the oil by a resistance coil, but this proved inadvisable on account of the unequal heating of the bath. Finally a resistance pad of asbestos wound with No. 28 Climax wire was tried and found to work most satisfactorily.

The following photograph is a view of the complete apparatus.

The space between the tank and the supporting bar was filled with a sheet of asbestos to prevent heat from causing expansion of the bar. Small holes were left in this packing to allow a sight on the trial piece.

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[1] This preliminary work was done by Karl Meuche as a thesis under the direction of the senior writer.

Choice of Oil for the Bath.—This afforded considerable trouble as the bath had to be a transparent one and remain so at the maximum temperatures used in the test. It also had to have a boiling point higher than the temperatures at which the expansion was to be determined. Lard oil, paraffine oil and olive oil were subjected to preliminary tests and, while transparent, were found to discolor at high heats and lose their transparency. Glycerine was then

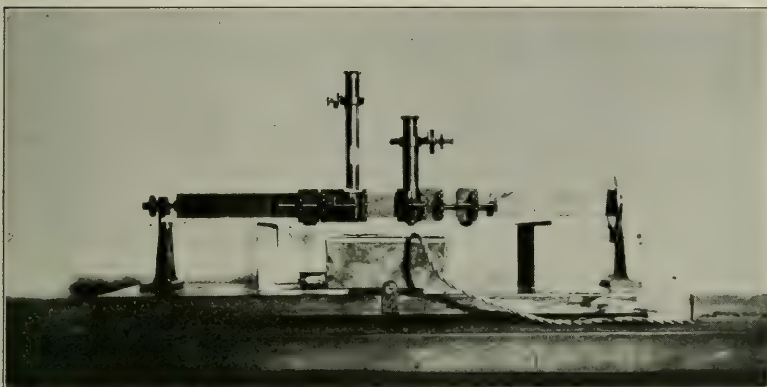

Fig. 1.—View showing rear of apparatus with tank.

tried and found very satisfactory, with the exception that it fumed at 150° C., clouding the lens of the microscope, thus dimming the focus.

Calculations.—The coefficient of expansion was figured from the formula

$$L = \frac{L_2 - L_1}{L_1(t_2 - t_1)},$$

where

L_2 = heated length in millimeters,
L_1 = original length in millimeters,
$(t_2 - t_1)$ = temperature range.

The Method Finally Adopted.—There are many faults in the method just described but the one which really

caused its abandonment was the limited heat range. We were unable to find a transparent oil which would remain fluid over a range of more than 180° C. and as it was desired to extend our readings to 500° C., we had to resort to the use of a small electric furnace.

As finally constructed, the furnace was an oblong box, built of 1/8″ asbestos lumber, and lined to a thickness of 3/4″ with a mixture of oxychloride cement and asbestos. The inside dimensions of this box are 1 1/2″ x 2″ x 6″. In the bottom of this box were placed the five heating coils, evenly spaced. Each coil consisted of about 12″ of doubled and twisted No. 28 Climax wire, wound on biscuit porcelain blocks, 1″ x 1 1/2″ x 1/8″, the wire being held in grooves on the blocks by means of a pair of similar porcelain blocks which were fastened one to each side of the core.

These five coils, connected in series, were sufficient to give a temperature in the furnace of 600° C. in about one and a half hours, with alternating current at 110 volts and 3 amperes, but if heated continuously much above 500° C., the coils would quickly burn out; hence, no measurements above 500° C. were attempted.

The coils being placed, the whole box was covered with a flat lid consisting of three layers of 1/8″ asbestos lumber, firmly fastened together. In this cover were two window spaces, 1 1/2″ square, and spaced about 4″ from center to center. These window spaces were covered with two thin sheets of mica, each fastened on either side of the middle layer of the asbestos cover.

To facilitate focusing, the furnace rested upon an asbestos platform, supported upon three leveling screws.

In series with the heating coils was a Thomson ammeter and a bank of lamps in parallel as external resistance.

In place of having two microscopes with movable cross-hairs, only one was used, the other microscope having fixed cross-hairs and no vernier. This simplified the recording of the data, for with the two verniers, it was always

necessary to record the direction as well as the number of divisions turned.

The rods carrying the microscopes were clamped to a horizontal rod in a horizontal position but at right angles to it. In this way the heat radiated from the furnace expanded the two rods, carrying the microscope farther from the first horizontal rod but did not alter the distance between them. The first horizontal rod and the upright carrying it were protected from these radiations by a large sheet of asbestos lumber placed vertically about midway between them and the furnace.

Calibrating the Micrometer.—To calibrate the micrometer, we used a brass standard meter bar graduated to millimeters and correct at 15° C. The number of divisions necessary to carry the cross-hairs from one side of one millimeter division to the corresponding side of the next were counted, being careful to always turn the micrometer in the same direction to avoid the back lash in the micrometer screw.

The first five counts were as follows:

Initial reading of micrometer.........	27	20.7	21	23.7	23.0
Final reading of micrometer..........	776	772.3	769	768.0	770.5
Divisions turned.....................	749	751.6	748	747.3	747.5

The meter bar was then shifted and a second division measured to eliminate the error in marking the meter-bar. These results follow:

Initial reading...........	18	16.3	16	17.7	16
Final reading.............	783	781.0	780	783.0	780
Divisions turned.........	765	764.7	764	765.3	764

These ten measurements were then averaged, giving 756.6 as the number of divisions equivalent to the distance between the millimeter division.

As the meter-bar is correct only at 15° C., and the readings were made at 28° C., a correction for temperature had to be made. This would make the distance between the millimeter divisions at 28° C. equal 1.000,244,4

mm. This quantity divided by the mean number of turns as above obtained makes each division equal to 0.001,322 mm. No correction was made for the expansion of the micrometer screw as it is also of brass and would probably expand the same as the meter-bar.

Had the correction for temperature for the meter-bar not been made, the value of one division would have been 0.001,321,7, a difference of 3 in the seventh decimal place for a range of 13° C.; hence, the value for the micrometer divisions was not calculated for each of the temperatures at which measurements were made.

A thermometer, suspended with the bulb just on a level with the object glass of the microscope when the temperature of the furnace was 500° C. and the room temperature 32° C., registered 44° C. The same thermometer, when suspended with the bulb just touching the micrometer cases and the furnace still at 500° C., registered 35.5° C. If the mean of these temperatures is taken, the correction of the micrometer should be for 25° C. instead of 13° C., as shown above. This would give a value of 0.001,322,3 for each division on the micrometer head.

SOURCE OF ERROR AND ATTEMPT TO OBVIATE THE SAME.

We were cognizant of several sources of error and attempted to obviate some of them. Some of the sources of error, which, because of their irregularity, cannot be allowed for in computation, are as follows:

Unequal Heating of the Test Piece.—On finding that the heat distribution did not vary more than 0.1° C. in any part of the furnace, the trial piece was held at the required temperature until no further elongation could be observed.

Expansion of the Bars which Supported the Microscopes.—This was, so far as could be determined, obviated by heat shields.

Back-lash in the Micrometer Screws.—This was ob-

viated by always turning the screw in the same direction when bringing the cross-hairs into position.

Errors in Measurement.—The marks on the trials, although made with a sharp steel point, were so wide that it was impossible to use them; hence, the microscopes were originally set with their field cross-hairs exactly 8 cm. apart. Small black dots in the lines made by the steel point were then so selected that a dot on one end of the tile was in an angle of the fixed cross-hairs and separated therefrom by a hair line of white; the other selected dot at the other end of the tile was similarly situated with regard to the movable cross-hairs when their intersection coincided with the vertical fixed cross-hairs of that microscope. These dots were then identified by their position relative to those of the more conspicuous dots. The only error thus introduced was in estimating the width of the hair line of white between the dot and cross-hair, but this could not be avoided and was found to be much less than the error introduced when the dot was allowed to touch or coincide with the cross-hairs.

Irregularity in the Observed Temperature.—Inasmuch as we made the reading at 100, 200, 300, 400 and 500° C., we had to use a thermocouple and galvanometer, and as the divisions on the galvanometer were rather large, an error of 5° C. may have been introduced in each of the observations. But as the current was nearly constant and to insure equal heating of the test pieces, the temperature had to be held over long periods of time, it is hardly probable that the error ever reached this limit.

Unequal Structure in the Trial Pieces.—It will be remembered that all of the trial pieces were made by being pressed by hand into plaster moulds. This method does not produce a uniform structure throughout the series, for the operator unconsciously treats each mixture according to its texture. Besides, hand-pressing of brickettes always produces structural defects.

It is proposed that in further work, a uniform struc-

ture in the trials will be approximated by casting the clay on a plaster slab, cutting the brickettes with a cutter similar to a cake cutter, and then pressing them under a uniform constant pressure by a method similar to that used in making brickettes for tensile strength tests.[1] It is also purposed to make the brickettes 25.0 cm. instead of 8 cm. long in order to reduce the accumulated error due to all sources.

DATA OBTAINED.

The coefficients here given are not offered as the exact coefficients for these body mixtures, for while the micrometer was accurately calibrated, in none of the readings was any attempt made to interpolate between divisions and in making the measurements, three check readings within one division were taken as final, so that so far as the real coefficient is concerned some error may have thus been introduced. However, it is believed that the results are relative and that they are valuable in discussing the subject in hand. Furthermore, considerable dependence can be placed in the actual values for the tests were repeated three times in all cases and in several, four and five times.

The data obtained are assembled in the following tables:

[1] Bull. 9, Illinois Geol. Surv., p. 163.

Original length, 80 mm. Each division turned = 0.001322 mm.

		100° C			200° C		300° C		400° C		500° C	
	Brickette No.	Room temp.	Temp. range	Coefficient	Temp. range	Coefficient	Temp. range	Coefficient	Temp. range	Coefficient	Temp. range	Coefficient
Series V	1	27	73	0.06338	173	0.06591	273	0.06295	373	0.06590	473	0.06533
	2	25	75	0.05288	175	0.05571	275	0.05283	375	0.05332	475	0.05323
	3	25	75	0.06610	175	0.06886	275	0.06730	375	0.06678	475	0.06749
	4	27	73	0.06338	173	0.06304	273	0.06416	373	0.06335	473	0.06323
	5	27	73	0.06338	173	0.06400	273	0.06416	373	0.06379	473	0.06393
	6	28	72	0.06656	172	0.06629	272	0.06618	372	0.06663	472	0.06617
	7	20	80	0.06817	180	0.06763	280	0.06787	380	0.06784	480	0.06747
	8	23	77	0.07082	177	0.07095	277	0.07099	377	0.07057	477	0.07067
	9	23	77	0.07313	177	0.07188	277	0.07158	377	0.07187	477	0.07176
Series W	1	25	75	0.06390	175	0.06421	275	0.06310	375	0.06346	475	0.06332
	2	23	77	0.06438	177	0.06535	277	0.06622	377	0.06571	477	0.06548
	3	22	78	0.06459	178	0.06357	278	0.06329	378	0.06316	478	0.06273
	4	23	73	0.06241	173	0.06178	273	0.06235	373	0.06247	473	0.06254
	5	23	77	0.06009	177	0.06442	277	0.06025	377	0.05907	477	0.06029
	6	23	77	0.06224	177	0.06018	277	0.06025	377	0.06049	477	0.06029
	7	25	75	0.06610	175	0.06610	275	0.06610	375	0.06610	475	0.06610
	8	27	73	0.06928	173	0.07068	273	0.07082	373	0.07082	473	0.07090
	9	29	71	0.07215	171	0.07150	271	0.07195	371	0.07126	471	0.07192
Series X	1	26	74	0.05806	174	0.05698	274	0.05729	374	0.05744	474	0.05752
	2	25	75	0.05288	175	0.06222	275	0.06009	375	0.05993	475	0.06018
	3	26	74	0.05582	174	0.06077	274	0.05850	374	0.05832	474	0.05859
	4	26	74	0.05806	174	0.05698	274	0.05789	374	0.05788	474	0.05787
	5	26	74	0.06476	174	0.06363	274	0.06333	374	0.06363	474	0.06380
	6	22	78	0.05508	178	0.05570	278	0.05573	378	0.05508	478	0.05558
	7	22	78	0.06144	178	0.06313	278	0.06301	378	0.06295	478	0.06290
	8	23	77	0.06653	177	0.06628	277	0.06622	377	0.06662	477	0.06651
	9	27	73	0.07244	173	0.07165	273	0.07082	373	0.07088	473	0.07119

Original length, 80 mm. Each division turned = 0.001322 mm.

		100° C			200° C		300° C		400° C		500° C	
	Brickette No.	Room temp.	Temp. range	Coefficient	Temp. range	Coefficient	Temp. range	Coefficient	Temp. range	Coefficient	Temp. range	Coefficient
Series Y	1	25	75	0.04627	175	0.04721	275	0.04627	375	0.04627	475	0.04627
	2	22	78	0.04449	178	0.04558	278	0.04518	378	0.04547	478	0.04529
	3	25	75	0.04406	175	0.04435	275	0.04387	375	0.04406	475	0.04418
	4	23	77	0.04721	177	0.04668	277	0.04936	377	0.04646	477	0.04732
	5	24	76	0.05217	176	0.05258	276	0.05209	376	0.05230	476	0.05242
	6	25	75	0.05510	175	0.05680	275	0.05588	375	0.05597	475	0.05566
	7	23	77	0.05365	177	0.05508	277	0.05429	377	0.05435	477	0.05439
	8	25	75	0.05723	175	0.05760	275	0.05709	375	0.05729	475	0.05740
	9	26	74	0.06700	174	0.06743	274	0.06694	374	0.06672	474	0.06700
Series Z	1	26	74	0.04689	174	0.04747	274	0.04704	374	0.04728	474	0.04706
	2	25	75	0.06389	175	0.06232	275	0.06268	375	0.06346	475	0.06332
	3	26	74	0.05806	174	0.05793	274	0.05789	374	0.05744	474	0.05752
	4	26	74	0.04913	174	0.04938	271	0.04945	374	0.04949	474	0.04951
	5	26	74	0.04019	174	0.04084	274	0.04087	374	0.04021	474	0.04097
	6	27	73	0.05429	173	0.05349	273	0.05326	373	0.05360	473	0.05380
	7	23	77	0.05794	177	0.05975	277	0.05787	373	0.05742	477	0.05785
	8	25	75	0.05728	175	0.05949	275	0.05703	375	0.05729	475	...
	9	26	74	0.04913	174	0.04938	274	0.04885	374	0.04904	474	0.04913
Series A	1					See V 1						
	2	25	75	0.07051	175	0.06988	275	0.06971	375	0.06963	475	0.06958
	3	28	72	0.06426	172	0.06533	272	0.06500	372	0.06530	472	0.06512
	4	28	72	0.06426	172	0.06437	272	0.06440	372	0.06441	472	0.06476
	5					See W 5						
	6	30	70	0.05366	170	0.05903	270	0.05880	370	0.05850	470	0.05907
	7	27	73	0.06620	173	0.06759	273	0.06659	373	0.06723	473	0.06743
	8	28	72	0.07115	172	0.07109	272	0.07108	372	0.07107	472	0.07142
	9					See X 9						

Original length, 80 mm. Each division turned = 0.001322 mm.

		100° C			200° C		300° C		400° C		500° C	
	Brickette No.	Room temp.	Temp range	Coefficient $\times 10^{-4}$	Temp. range	Coefficient $\times 10^{-4}$	Temp. range	Coefficient $\times 10^{-4}$	Temp. range	Coefficient $\times 10^{-4}$	Temp. range	Coefficient $\times 10^{-4}$
Series B	1					See W 1						
	2	30	70	0.06610	170	0.06610	270	0.06610	370	0.06387	470	0.06504
	3	26	74	0.06030	174	0.05983	274	0.05971	374	0.05965	474	0.05926
	4	26	74	0.05888	174	0.05699	274	0.05730	374	0.05744	474	0.05752
	5	23	77	0.05780	177	0.05788	277	0.05787	377	0.05753	477	0.05785
	6	24	76	0.05217	176	0.05539	276	0.05628	376	0.05669	476	0.05696
	7	27	74	0.04913	174	0.05390	274	0.05488	374	0.05523	474	0.05578
	8	25	75	0.04846	175	0.05265	275	0.05283	375	0.05288	475	0.05323
	9					See Z 9						
Series C	1					See X 1						
	2	28	72	0.05736	172	0.05801	272	0.05772	372	0.05775	472	0.05734
	3					See Y 3						
	4	25	75	0.04186	175	0.04155	275	0.04206	375	0.04186	475	0.04209
	5					See Z 5						
	6	26	74	0.06253	174	0.06268	274	0.06212	374	0.06274	474	0.06240
	7	28	72	0.06885	172	0.06725	272	0.06926	372	0.06885	472	0.06862
	8	27	73	0.07017	173	0.06973	273	0.06901	373	0.06911	473	0.06917
	9	27	73	0.06791	173	0.06782	273	0.06779	373	0.06734	473	0.06748
Series D	1					See Y 1						
	2	29	71	0.05819	171	0.05895	271	0.05793	371	0.05790	471	0.05799
	3	29	71	0.06051	171	0.05992	271	0.05976	371	0.05790	471	0.05939
	4	27	73	0.06338	173	0.06400	273	0.06416	373	0.06380	473	0.06393
	5	28	72	0.06885	172	0.06821	272	0.06809	372	0.06797	472	0.06748
	6	28	72	0.06197	172	0.06245	272	0.06192	372	0.06219	472	0.06232
	7	26	74	0.06476	174	0.06363	274	0.06332	374	0.06362	474	0.06356
	8	24	76	0.06958	176	0.06948	276	0.06945	376	0.06945	476	0.06943
	9	26	74	0.07146	174	0.07123	274	0.07117	374	0.07158	474	0.07199

The values for "Elongation" were obtained by multiplying "Divisions Turned" by the value of each division.

The values in the column headed "Coefficient Linear 10^{-4}" are obtained from the following equation,

$$\frac{E}{L \times t} = C,$$

where

E = elongation,

L = 80 mm., the length at initial temperature,

t = temperature range,

C = the mean coefficient thus obtained.

To economize space in the table, this coefficient has been multiplied by 10,000.

To assist in interpreting this data, a plaster model was made (Fig. 2). A triaxial diagram was first laid out on a level table top and the bodies located thereon. At each point, representing a body mixture, a hole was bored into which was fitted a wooden peg. These pegs were cut in lengths proportional to the coefficient of the body represented. In order that the model might not be inordinately high, a flat cut of three inches was made on each peg.

The method of finding the proper length of peg to represent Body V 9, for illustration, whose coefficient of expansion is 0.000,007,2, is as follows:

$$0.000{,}007{,}2 \times 1{,}000{,}000.0'' = 7.2''.$$
$$7.2'' - 3'' = 4.2''.$$

The peg would be cut to such a length that when driven into the table, it would project 4.2″ above the surface.

When all the pegs had been driven, the space between them was filled with clay and the clay worked down to a smooth surface just touching the tops of the various pegs. From this, a plaster model was cast.

DISCUSSION OF DATA.

General Observations.

(1) The contour of the model is not a plain, as one would be led to expect from Burt's expansion equivalents.

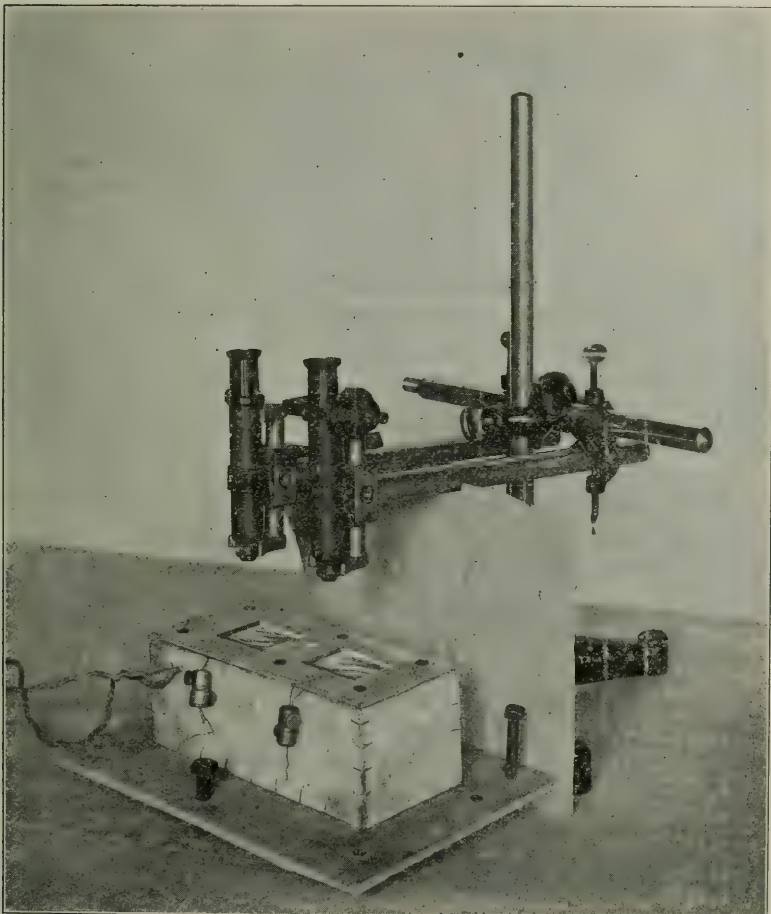

Fig. 2.

(2) The body having the lowest coefficient is not the one containing the most clay or the most feldspar as would be expected from Seger's Laws.

(3) The body containing 50 per cent. feldspar has nearly as great a coefficient as has the body containing 70 per cent. of flint, the coefficient being 0.000,007,1 and 0.000,007,2 respectively.

(4) Probably the most striking feature of the whole model is the relatively low coefficient of all the bodies containing between 25 per cent. to 30 per cent. of feldspar.

(5) The minimum coefficient found in this study was that of the body containing 30 per cent. feldspar, 30 per cent. flint and 40 per cent. clay. In the immediate neighborhood of this body there were five others, the coefficients of expansion of which were nearly as low.

Discussion of Data in Reference to Seger's Laws.—We take it that Seger's laws, derived from experiments with white ware bodies, are not to be expected to apply much outside of the area of practical white ware body compositions, *i. e.*, 8–20 per cent. feldspar, 40–52 per cent. clay, and 28–52 per cent. flint.

(1) Within these limits, when flint is less than 45 per cent., we find that with any mixture of flint and feldspar, or even when added at the expense of flint—clay slightly *increases* rather than decreases the coefficient of expansion. But even though clay does increase the coefficient, it will also cause crazing.[1]

(2) While maintaining flint constant, addition of clay at the expense of feldspar, within these limits, also increases the coefficient, but does not materially affect the glaze fit, *i. e.*, if there is perfect accord between the body and glaze, it will not be jeopardized by substituting clay for feldspar, provided always that the total flint content is not altered. Yet such substitution would cause an increase in the coefficient of expansion.

(3) Upon adding feldspar to any given ratio of flint

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[1] See p. 576, Vol. II, Seger's Collected Writings.

to clay, within these same limits, or keeping clay constant and adding feldspar at the expense of flint, decreases the coefficient and carries us from the area of fit to that of crazing. This is as Seger thought.

(4) Flint (up to 45 per cent.) added to any given ratio of clay to feldspar within these same limits, or when substituted for clay, while maintaining feldspar constant, slightly *decreases* the coefficient and at the same time carries us from the area of crazing into fit; while if clay is maintained constant and flint is substituted for feldspar, the coefficient is *increased*, and at the same time the tendency to craze is overcome.

(5) We find then that the bodies within this limited area (the area of practical pottery bodies), feldspar is most active in reducing the coefficient of expansion, and the clay the most active in raising it, while flint seems to have but slight effect one way or the other, until it exceeds 50 per cent. of the total batch.

(6) Seger says ("Seger's Collected Writings," Vol. II, p. 576): "By increasing the clay bonding material in a body, the expansion of the same with a rise of temperature is decreased." This we have not found to be true, if this statement meant that the clay is to be added to an already satisfactory body in amounts only sufficient to cause crazing. It is true only after the total clay content exceeds 55 per cent. of the batch.

(7) Again, on the same page, we find the statement that "An increase of feldspar (constant ratio of clay to quartz), therefore, acts also in direction of reducing the expansion or contraction of the body of the ware." This is clearly demonstrated by our data.

(8) In reference to flint (quartz), Seger says: "By raising the content of quartz, the coefficient of expansion of the body is raised." We have not found this to be true within practical working limits, but it undoubtedly is true after the flint has become 50 per cent. or more of the mix.

(9) It may be said then that starting with a practical

working body and keeping within practical working limits, our data supports Seger's hypothesis only in one instance, *i. e.*, feldspar does decrease the coefficient of expansion. Within these limits, however, clay increases while flint slightly diminishes the coefficient, effects quite contrary to what Seger supposed.

(10) Examining the coefficient along the craze line as determined by Dr. Hecht, we find the following bodies situated on each side of the craze line:

Crazed body	coefficient	Fit body	coefficient
W-1	0.0000064	V-2	0.0000053
B-2	0.0000066	A-2	0.0000069
Y-2	0.0000060	W-3	0.0000063
C-3	0.0000044	B-3	0.0000060
Y-3	0.0000044	X-3	0.0000058
Z-3	0.0000058	C-4	0.0000042
D-3	0.000060	Y-4	0.0000047

It will be seen that three of the seven bodies in the above table, under the heading "Crazed," have a higher coefficient than the bodies in the corresponding series which lie within the area of "Fit," also body Z-9, containing 30 per cent. feldspar, 20 per cent. clay and 50 per cent. flint, is on the opposite side of the diagram from where crazing is to be expected and has a coefficient of only 0.000,004,9, or less than most of those listed above as "Crazed."

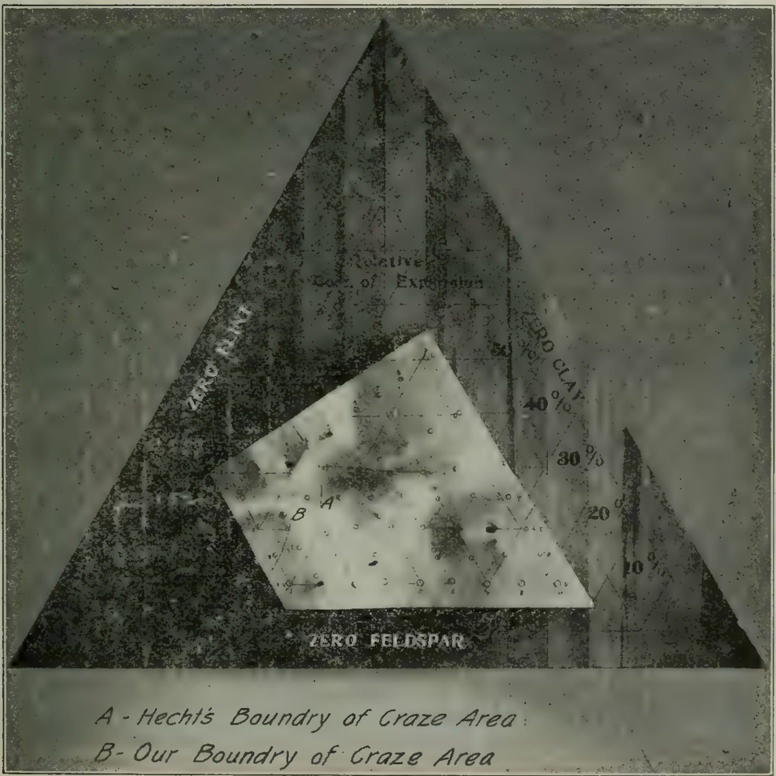

ZERO FLINT
ZERO CLAY
ZERO FELDSPAR
40 %
30 %
20 %
A
B
A - Hecht's Boundry of Craze Area
B - Our Boundry of Craze Area

Fig 3.

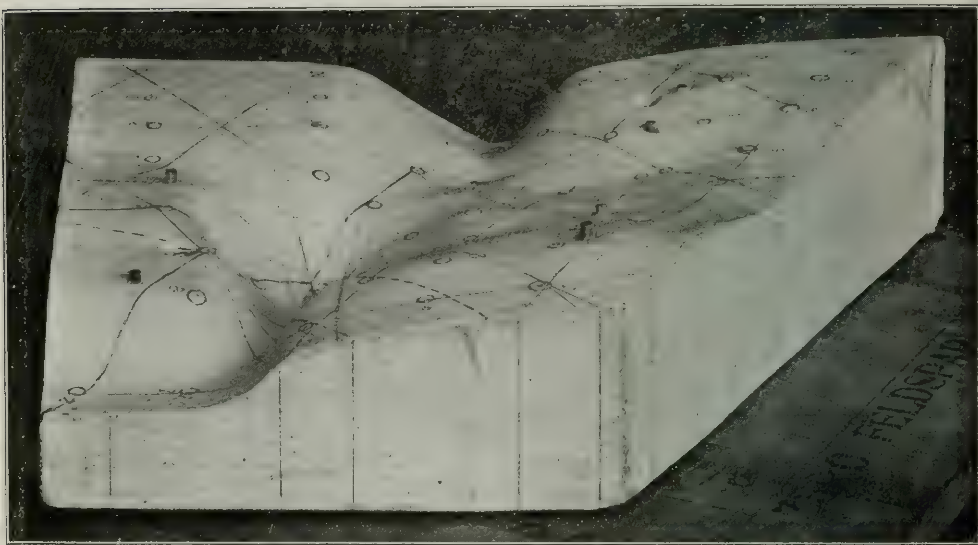


Fig. 3*a*.

Discussing of Data in Reference to the Whole Field.

(1) Starting with the body having the lowest coefficient of expansion (30 per cent. each of flint and feldspar and 40 per cent. of clay) and noting the effect of increase of flint, keeping the feldspar and clay always in the same proportion, we find:

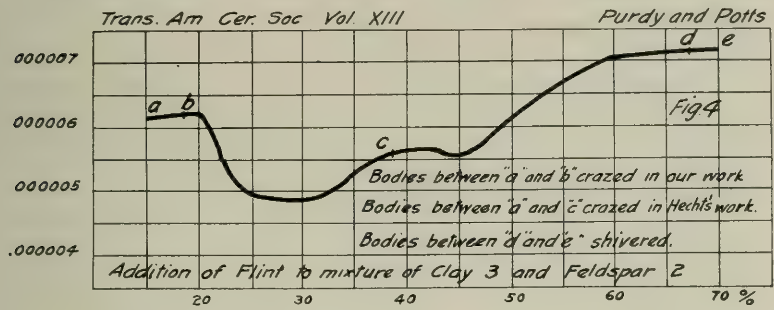
(*a*) The first 5 per cent. addition of flint causes an abrupt rise in coefficient from 0.000,004,1 to 0.000,005,2.

(*b*) With the next 5 per cent. addition of flint, the increase in coefficient continues, but less abruptly.

(*c*) With a further addition of 5 per cent. of flint to this minimum coefficient body, making a total of 45 per cent. flint, we find a slight decrease.

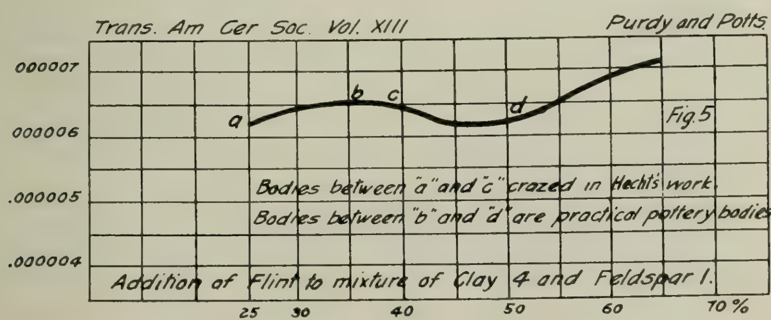
(*d*) But with further addition of flint (from 45 to 60 per cent.) we find there is a comparatively large increase in coefficient.

The history of an effect of flint similar to this is shown in Fig. 4.



(2) The effect of addition of flint to a mixture of 4 of clay and 1 of feldspar is to be seen in Fig. 5.

When flint is 40 per cent., the clay and feldspar would be 48 and 12 per cent., respectively. It is to be noted, therefore, that this curve passes through the middle of the area of practical pottery bodies.

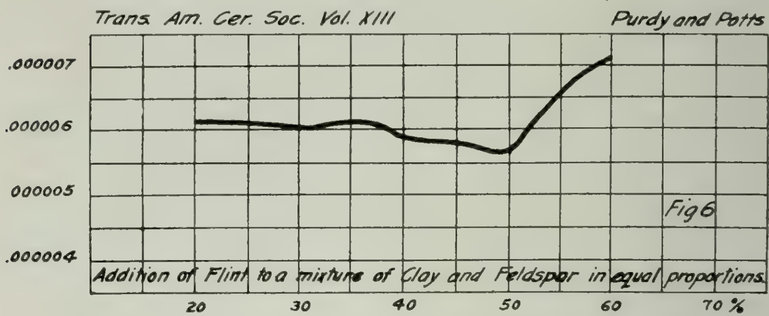


(3) The effect of addition of flint to a mixture of clay and feldspar in equal proportion is traced in Fig. 6.

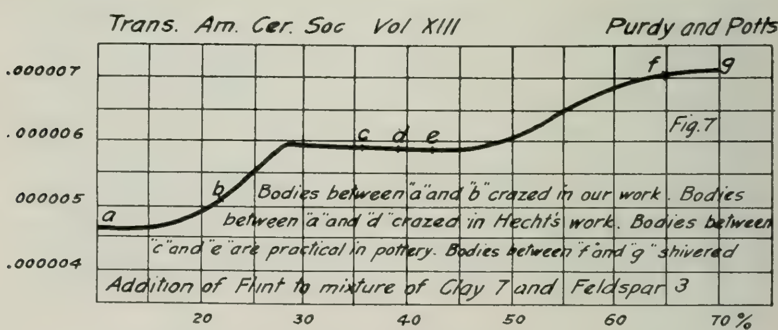
(4) The effect of addition of flint to a mixture of 7 of clay and 3 of feldspar is shown in Fig. 7.

(5) The highest coefficient of expansion was obtained with the highest content of flint and with it shivering of the glaze occurred. This is in harmony with Seger's views.

But, additions of flint did not, at all times, increase the coefficient of expansion, nor can the ability of a given glaze to stand without crazing be attributed to any particular coefficient of expansion of the body.



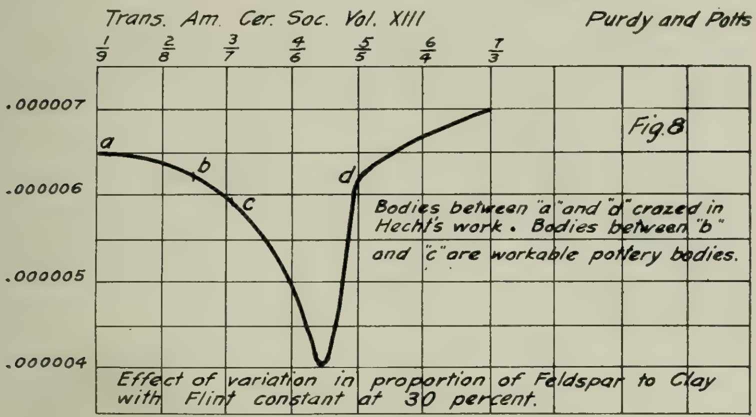
(6) Neither Hecht nor we found crazing on the body which, in this study, has the lowest coefficient of expansion, while several bodies with a much higher coefficient did cause crazing.



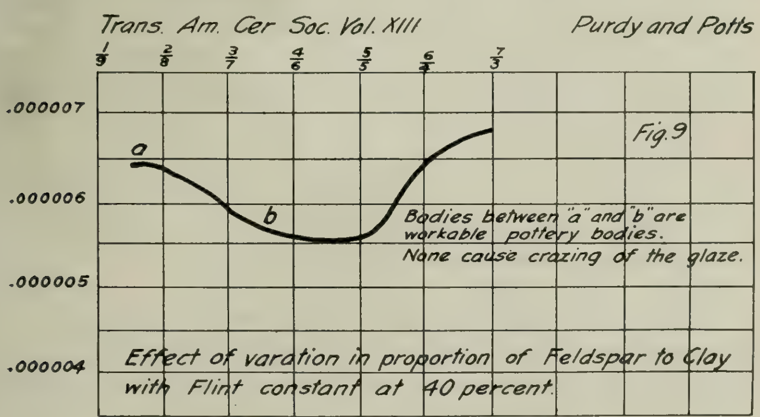
(7) Furthermore, with flint constant at 30 per cent. we find the coefficient varying with variations in proportion of clay to feldspar (as traced in Fig. 8) much more abruptly than it did with variations in content of flint.

(8) With flint constant at 40 per cent. we find the effect of variation in clay and feldspar as is traced in Fig. 9.

From the curves it will be seen that the maximum expansion occurs when any one of the components of the mixture is high but that the amount of each required to



produce an equally large coefficient differs. For instance, a coefficient of expansion of about 0.0,000,065 was obtained in bodies containing 55 of flint, 45 of feldspar and 50 of



clay respectively, and, furthermore, the expansion of all the 35 per cent. feldspar bodies is nearly the same as is the case in those containing 55 per cent. of flint, while

to have high expansion due to high clay the feldspar must be low. These observations lead to the obvious conclusion that in amounts above 30 per cent., feldspar is more of a factor in causing an increase in the coefficient of expansion than is flint or clay. In fact, the body with 50 per cent. feldspar has the same coefficients as the one containing 70 per cent. flint, the clay content in each being the same.

(9) From Plate 11, it is to be seen that to obtain a minimum coefficient of expansion requires a progressively decreasing ratio of flint to feldspar with each increase in content of clay. As the clay increases from 25 to 60 per cent., the feldspar content of the minimum coefficient bodies varies from 30 to 25 per cent., producing the valley which, in Fig. 4, is seen to run nearly parallel to the feldspar base.

CONCLUSIONS.

(1) It appears that the coefficient of expansion of white ware body mixtures is more a function of the structure attained than of their mineral constitution.

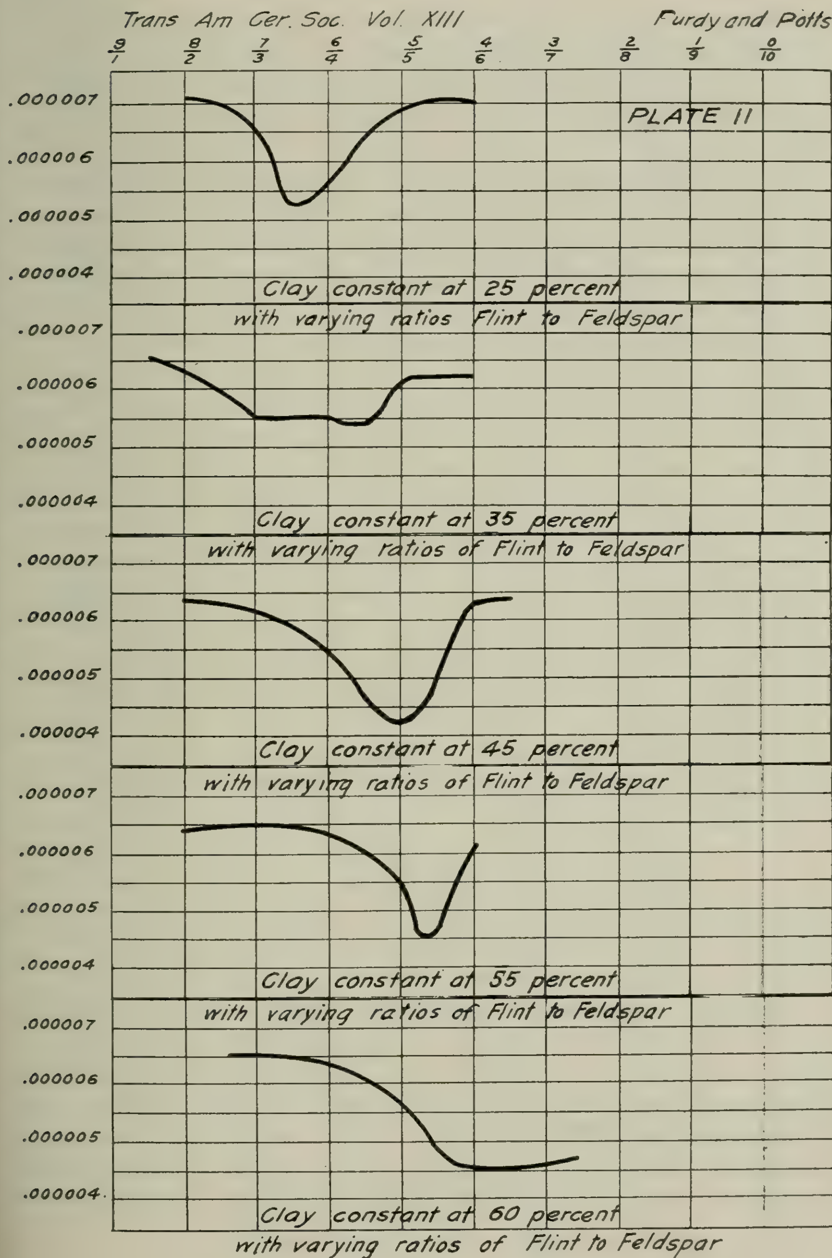
(*a*) As the feldspar increases above 30 per cent., the development of bleb structure increases quite rapidly. In this series, the body containing 50 per cent. feldspar had developed a bleb structure at cone 10 sufficient to cause it to be swollen.

(*b*) As the feldspar decreases from 25 to 10 per cent., the volume of open pores at cone 10 increases.

(*c*) The bodies containing high flint or high clay will be more porous than the one in which the two mineral substances are in nearly equal proportions.

(*d*) Electrical porcelain bodies of the highest dielectric strength contain from 25 to 35 per cent. feldspar, and it has been repeatedly proven by Mr. Watts that the dielectric strength of porcelain increases with increase in density of structure.

(*e*) We are unable to even conjecture what the influence of degree of vitrification will be on a given body


Trans Am Cer. Soc. Vol. XIII
Purdy and Potts
9/1 8/2 7/3 6/4 5/5 4/6 3/7 2/8 1/9 0/10
PLATE II
.000007
.000006
.000005
.000004
Clay constant at 25 percent
with varying ratios Flint to Feldspar
Clay constant at 35 percent
with varying ratios of Flint to Feldspar
Clay constant at 45 percent
with varying ratios of Flint to Feldspar
Clay constant at 55 percent
with varying ratios of Flint to Feldspar
Clay constant at 60 percent
with varying ratios of Flint to Feldspar

mixture, but if this supposition proves to be true, we will find in the work now in progress that with increasing heat treatment, the line of minimum coefficient of expansion will progress from high feldspar to lower feldspar content.

(2) While we feel unwarranted in saying that difference in coefficient of expansion of the body and the glaze is wholly without effect on glaze fit, we certainly are forced to recognize that the difference in expansion is neither the sole nor the most effective cause.

Even Seger's rules, as he states them, are contradictory in logic. He says that if the glaze has a greater contraction than the body, the glaze, on cooling, would crack. That much of his argument is quite plausible. But if the glaze has the larger coefficient of contraction, it must also have the larger coefficient of expansion, and, hence, to be logical in his conceptions of the situation, he should have conceded that the glaze would shiver when the ware was heated. But since no one has yet found crazing and shivering under one and the same set of conditions, we must conclude that Seger's ideas concerning the cause of crazing is neither logical in conception nor in harmony with facts.

(3) Since in other studies, we have found, as did Hecht, that a white ware glaze stood equally well on bodies ranging from those high in feldspar, which develop a vesicular structure when vitrified, to those high in flint which, with the same biscuit heat treatment, are not vitrified, *i. e.*, still have open pores, it might be argued that porosity, whether sealed or open, facilitates perfect adjustment between the glaze and body. And, since our observations concerning coefficient of expansion lead us to conclude that it was more a function of the density of structure than of composition and since we find the higher feldspar-flint bodies have more uniformly high coefficient of expansion, we would have both perfect glaze fit and high coefficient of expansion function of the same factor, *i. e.*, density of structure, but not necessarily of one another.

Not having data on the comparative structural density of our trial bodies, we do not feel warranted in conjecturing in just what way these three factors may be interrelated.

(4) If our findings are confirmed by those obtained on bodies made from other materials, we can say that to produce bodies of low coefficient of expansion and contraction at cone 10, the feldspar content should be between 25 and 30 per cent. of the total mixture, and that the clay should not be lower than 40 per cent. And if our deduction concerning the cause of differences in coefficient of expansion proves to be true, it would be found advantageous in the making of low coefficient ware to employ every device, mechanical or otherwise, that would increase the structural density.

Lag in the Trial Pieces.—No lag in contraction, or permanent set, as it has been called, could be detected, although every night the last piece tested was left in the furnace and remeasured after 15 hours' cooling. We never failed to find that the test pieces had returned to exactly the same length as before heating.

T. G. Bedford writes of his experience: "There seems to have been permanent changes in the length of the tube during the course of the experiments, but these changes are very small and apparently irregular. . . . . The total increase in length at 0° from March 13th to April 18th was 0.02 per cent."

DISCUSSION.

Mr. Binns: I am interested in the model. It elucidates in such a novel manner the fact that the excess of any one component produces the same coefficient of expansion as the excess of another.

We want data of this kind to show the actual behavior of the body mixture, apart from the glaze.

In dealing with any body under a given glaze, you cannot ignore the fact that the glaze is feeding on the body-substance, dissolving certain parts of the body and incorporating them into its own nature. A body

high in flint is more apt to do so than is one high in clay or in feldspar. That, I think, accounts for the fact that we do not find the same behavior in glazes on bodies as would be indicated by this splendid diagram.

You are aware that a large amount of German product is imported because of its low coefficient of expansion, and that our potters have been only comparatively successful in competing with these imported articles. All kinds of hypotheses have been put forth as to the ingredients used. We have analyzed them and found nothing there but normal ingredients. By means of this diagram, I think that we can, however, approach pretty near to a satisfactory solution of the problem.

Mr. Purdy: We have made little porcelain crucibles out of these same bodies (burned at cone 10), which, when placed in a Caulkins kiln and heated to redness, and then ducked in water, failed to show any relation between the coefficient of expansion and contraction and ability to stand that test.

Mr. Parmelee: Crazing is known to be a very complicated thing, and the fact that we get this scirrhous surface may be explained on the ground that elasticity is a much greater factor than it has hitherto been considered to be in crazing of a glaze.

SUBMITTED AFTER HAVING READ THE PAPER.

Mr. Watts: It is interesting to note that while many areas exist within which a slight change in composition might cause a great change in coefficient of expansion, these areas all lie outside the limits of practical white ware bodies.

A comparison of the findings of these investigators working with American materials at cone 10 and my own findings when using European materials and firing at cone 15 is very interesting as throwing some light on the possible difference in opinions existing as to the rôle of the various constituents in the matured body.

These investigators find that, within white ware limits, an increase in feldspar at the expense of flint, with clay remaining constant, causes a decrease in coefficient of expansion. This checks my findings at cone 15 on bodies of these compositions.

Within the above limits these investigators find that an increase of feldspar at the expense of clay, with flint remaining constant, decreases the coefficient of expansion, but does not affect the glaze fit as it would be expected to do from Seger's laws.

My findings at cone 15 indicate that very little change in coefficient of expansion would result from the above change in composition.

This difference in action of clay at cone 10 and at cone 15 on given mixtures of flint and feldspar can be accounted for by the fact that at cone 10 the formation of sillimanite by decomposition of clay substance has occurred in very slight degree, while at cone 15 it has progressed much farther and often, according to Zoellner, amounting to a change of 25 per cent. of the clay substance present. If this is the cause of the difference in coefficient at the two temperatures, the sillimanite must possess a very low coefficient of expansion, since it counteracts the influence of the remaining clay substance toward increasing the coefficient of expansion as it does at cone 10 when replacing feldspar.

These investigators find that within the practical limits of white ware body compositions at cone 10 with feldspar constant, an increase of clay at the expense of flint gives a slight increase in the coefficient of expansion.

I found at cone 15 that under such conditions and within these limits a very pronounced decrease in coefficient was obtained.

Why flint should be more active at cone 15 than at cone 10, I cannot explain. We know, however, that a glass containing a given amount of flint possesses a much higher coefficient of expansion than a porcelain containing the same amount of flint.

A comparative study of bodies fired at cone 10 and cone 15 indicates that at cone 10 the minimum coefficient of expansion is found in bodies containing about 30 per cent. feldspar while at cone 15 the bodies with minimum coefficient of expansion contain about 15 per cent. feldspar. Along either of the above lines the coefficient of expansion increases with increase of flint, although in the cone 10 study this increase is not a uniform rise but, nevertheless, a general one from one extreme of the study to the other. It must be borne in mind that this 30 per cent. feldspar content at cone 10 lies outside the white ware area and, hence, is not used in comparison of bodies in that class. I merely cite the general fact that in bodies of the minimum coefficient of expansion at the two named temperatures, the laws of Seger hold good, *i. e.*, that flint replacing clay increases the coefficient of expansion.

NOTE WRITTEN AFTER READING DISCUSSION BY MR. WATTS.

Mr. Potts: In order to make clearer the relation of Mr. Watts' series to our own and to compare the results obtained under widely different conditions, I have prepared the curves shown in Plate. I. Mr. Watts' curves are shown in full black lines and the points determined by him are represented by solid black dots, while our results are shown by dotted lines and our points by small circles.

The Effect of Variation in Ratio of Feldspar to Flint with Clay Constant.—Within the area investigated by Mr. Watts, three points are evident.

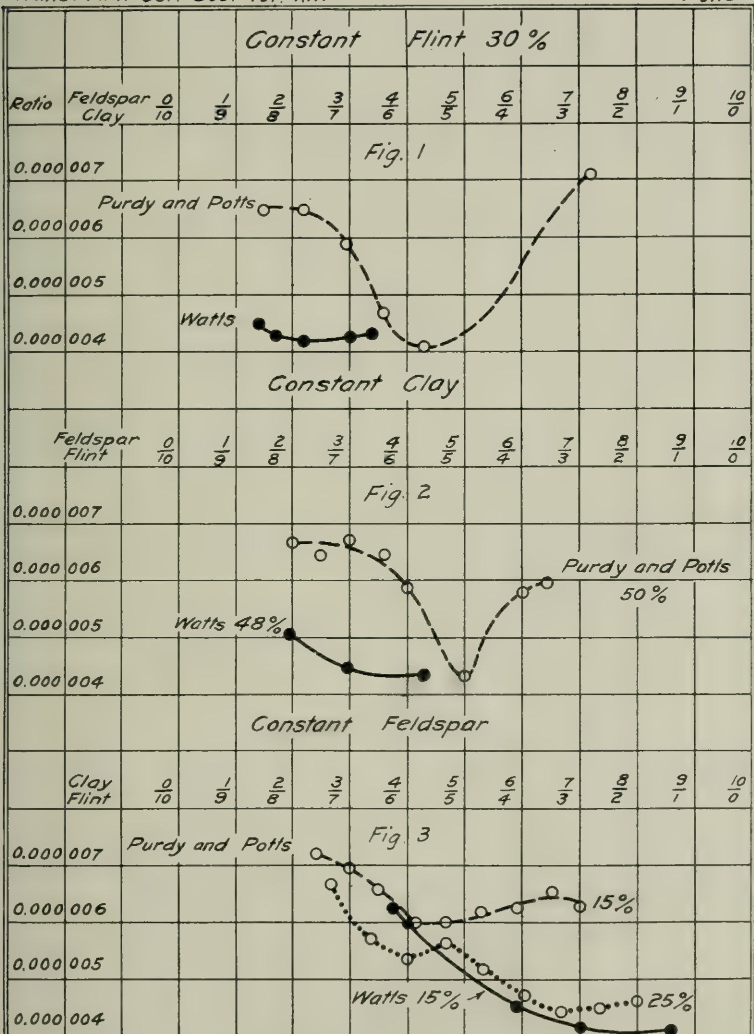
(1) The general trend of the curves is the same.

(2) Mr. Watts' curve has reached its minimum with feldspar and flint in the ratio of 4/6, while our curve continues to fall with increase of feldspar until the ratio of feldspar to flint is 5/5.

(3) While in the mixtures he studied, he obtained lower coefficients than did we, his minimum coefficient is not lower than that which we found.

Plate I

Trans. Am. Cer. Soc. Vol. XIII Potts



It is well known that at cone 15 the same degree of vitrification and the same development of vesicular structure is obtained with considerably less feldspar than at cone 10. This being the case, these curves show plainly that Mr. Watts' work checks our findings not only as to the fact that within the area of white ware bodies, feldspar decreases the coefficient of expansion but also that the coefficient of expansion is a function of the density of the structure.

At the same time it will be seen that the data of these two papers do not support Mr. Stanley Burt's statement "That up to fairly complete vitrification, the higher we fire, the greater the coefficient" (*Trans. A. C. S.*, Vol. V, p. 342), or the somewhat changed form of the same statement as it appears in Vol. VII, p. 125 of the same *Transactions*. In fact, we find, as did Watts, that the coefficient of expansion decreases as we approach vitrification.

The Effect of Variation in Ratio of Feldspar to Clay with Flint Constant.—The curves showing the effect of these variations tell the same story, *i. e.*, the mixture having the lowest coefficient at cone 15 contains less feldspar than does the one with lowest coefficient at cone 10.

It is very unfortunate that Mr. Watts' series are so short, because, although the evidence is strong that his work supports our findings, it would be much more satisfactory, especially in this matter of the relation of the coefficient of expansion to density of structure, if his curves extended far enough beyond the minimum point to show beyond dispute that an increase of either feldspar or clay would cause an increase in the coefficient of expansion.

It is indeed going quite far into the realm of pure speculation when Mr. Watts attempts to account for the difference in the action of clay under different heat treatments by the formation of sillimanite.

This is amply shown by comparing the curve for constant flint with that for constant clay and noting that there is the same sort of variation in coefficient when the clay is

constant as when the clay is varying. It will take stronger proof than is now at hand to convince me that the formation of sillimanite *per se* is a factor in reducing the coefficient of expansion.

The Effect of Variation in Ratio of Flint to Clay with Feldspar Constant.—Mr. Watts is surely in error when he says: "We know, however, that a glass containing a given amount of flint possesses a much higher coefficient of expansion than a porcelain containing the same amount of flint." This notion of Mr. Watts' is contrary to the function Seger assigns to the flint used in the body and in the glaze.

I wonder, too, if Mr Watts forgets that silica glass, which Mr. Stanley Burt describes as "fused pure silica" (Vol. V, p. 341, *Trans. A. C. S.*) and which Mr. Watts himself used in the construction of his apparatus, has an extremely low coefficient of expansion.

As for the apparent contradiction in the result obtained in our separate investigations, a study of the two sets of data will show that the contradiction is apparent rather than real.

It will be seen that at the high flint end of Mr. Watts' constant feldspar curve, we each obtained exactly the same values for the coefficient in spite of the difference in the heat treatment which the test pieces received.

It is equally evident that our curve showing ratios of clay to flint of less than 4/6 is merely a continuation of his curve.

The curves do diverge as the clay increases, but, in view of what has been said regarding the relation between density and coefficient of expansion, it is evident why this divergence should be as it is. It is doubtless due to the greater density caused by the more intense heat treatment.

As further evidence of this, the curve showing the coefficient of the bodies containing 25 per cent. of feldspar has been drawn. A glance will show that with clay to flint in ratios greater than 1 : 1, this curve agrees remark-

ably well with that obtained by Mr. Watts with less feldspar, and a higher heat treatment.

From the very close agreement between Mr. Watts' and our results, it is very evident that there is little ground for difference in opinion as to the rôle played by the various constituents of the matured body. If by matured body is meant the body which is so burned as to have attained the greatest possible density, then the indications are that we agree. Mr. Watts has failed to furnish any data on which to discuss the rôle of the various ingredients in any other than thoroughly vitrified bodies.

It is true that at cone 10 the areas in which slight changes in composition cause a comparatively large change in coefficient of expansion do lie outside of the area of practical white ware pottery bodies. But if the curve showing the effect of variation in ratio of clay to flint is consulted, it will be seen that within the areas of practical bodies, which is represented by the high clay end of the curves, a difference in heat treatment from cone 10 to cone 15 has a more marked effect than has an increase in the feldspar content from 15 to 25 per cent.

In our paper and in this discussion, we have purposely refrained from committing ourselves on the supposed relation between glaze fit and the coefficient of expansion. The data at hand, however, do indicate that there is no such close relation as has been previously held, but we do not wish it to be inferred from this that we believe the difference between the coefficient of the body and that of the glaze is wholly without effect in the control of glaze fit.

Prof. Binns: I have enjoyed the presentation of this paper and particularly the novel and graphic form of the solid diagram. As to the facts there is no room for discussion, presuming the data to be accurate. I do not think the method adopted for measurement is the most accurate possible but Mr. Watts worked, presumably, with another method and secured approximately concordant results. I do not recall any statement as to the

temperature at which the data for the solid diagram were obtained, or perhaps the figures taken were the averages at all the temperatures dealt with. I should prefer to see the work done at a rise of 100 degrees only as it is between 0 degrees and 100 degrees that crazing occurs and I doubt if the behavior of a given body at 400 degrees or 500 degrees has any necessary bearing on the case.

I am glad to see this work as continuing the study of coefficients. There have been some less important attacks upon the problem but before accepting any new theory the question herein propounded must be answered several times in the same way.

Mr. Potts: I am pleased to have Professor Binns discuss this paper in the way he does, as his remarks show plainly that some points cannot be too strongly emphasized. For example, a considerable portion of the paper is devoted to a discussion of the inaccuracies of the data and the weak points in our method of measurement. But in spite of these, we still have confidence in the relative value of the results obtained and Mr. Watts' results only strengthen that confidence. However, we are not yet satisfied, and as is plainly stated in the paper, plans are under way for a much more extensive, and, we hope, more accurate investigation of the whole subject.

As to the temperature range used, it must be borne in mind that at the outset we did not confine ourselves to an investigation of the subject of crazing alone, but sought to obtain some light on such subjects as, "A Change of Coefficient with Rise of Temperature," "Permanent Set, or Lag in Contraction," and the like, all of which seemed to require as wide a temperature range as possible.

In reply to Professor Binns' inferred question as to the source of data for the solid diagram, I will merely point to the tables where it will be plainly evident that it mattered little which set of results were taken: as a matter of fact, however, the data used are averages of all the results.

The most surprising feature of Professor Binns' dis-

cussion, however, is the manner in which he utterly ignores the conclusions drawn. These conclusions were purposely expressed in very broad and noncommittal terms, because the results obtained surprised even the investigators, but their trend was so persistently evident as to demand expression. Is it possible that, in our desire to express no more than seemed necessary and this only in very general language, we have so concealed the points that Professor Binns has missed them entirely?

Mr. Binns: Mr. Potts says "we are not satisfied" and still he asks my attention to certain "conclusions." I do not admit conclusions any more than Mr. Potts does. I admit important evidence but am not yet ready to bring in a verdict.

By this I do not mean to criticize or to belittle the work done. It is most excellent but the evidence offered is so radical and so subversive of that which most of us have held that I think it should be abundantly and extensively confirmed before a final judgment is passed.

Mr. Bleininger: I have had the opportunity to read carefully the text of this interesting article, through the courtesy of Professor Purdy. In this connection I must confess that I was preparing to criticize the method of determining the coefficient employed by Messrs. Purdy and Potts based on the objection that the temperature in the box could not have been uniform. But while I still think that a resistance pyrometer[1] using a silver-constantan couple would have more truly represented the average temperature and while, perhaps, the method was not entirely free from optical error due to parallax, it is evident that the results are concordant and are exactly what Professor Purdy claims them to be. Both, the work, and the presentation of the results, and of the conclusions, combine to give us a very fine research upon the successful finish of which the authors are to be congratulated. They deserve the thanks of the Society for this careful and logical contribution.

In the face of their figures any theoretical criticism would be out of place, for they represent scientific facts which silence assumptions of any kind.

[1] See "Measurement of High Temp.," by J. K. Clement, Trans. A. C. S., Vol. XI, p. 457 (Ed.).

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A STUDY OF THE RATTLER TEST FOR PAVING BRICK

BY

M. W. BLAIR AND EDWARD ORTON, JR.

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A STUDY OF THE RATTLER TEST FOR PAVING BRICK.

By M. W. Blair and Edward Orton, Jr.

Introduction.

The rattler test for determining the relative resistance of paving bricks to impact and abrasion has been in use since the late eighties, when the paving of streets with brick began to make headway in America. The simplicity and competitive features of this mode of testing has from the first strongly appealed to all concerned. The early mode of testing was to put two or more bricks of as many different samples as were in competition, into a rattler of appropriate size, fill the bulk of the residual space with scrap iron of any sort available, and rotate the barrel at any convenient speed for from one to six hours, and determine the losses of each variety. Of course, under such conditions, there was no likelihood of the original operator being able to check his results, and no possibility of rattler tests made in different places being compared at all.

The first efforts at standardization of the test began in 1895 and resulted in 1901 in the rather wide acceptance of a method known as the N. B. M. A. test. For a much fuller historical statement of the beginnings of the rattler test, see the chapter by A. N. Talbot, Bulletin 9, Geological Survey of Illinois.

This standard has been the criterion upon which hundreds of millions of paving bricks have been judged. It has done great good, by reducing to comparative order a condition which had been chaotic. It was recognized by the committee of engineers and manufacturers who framed the N. B. M. A. specifications, that these were not as full and well defined as was desirable, but it was considered unwise and premature to attempt too rigid and precise definition for fear of stopping the use of the test entirely. Some of the points left open or poorly defined in these specifications have since been shown to be capable of exerting a very appreciable disturbing effect.

Criticisms of the rattler test have, therefore, been occurring at all times since its adoption, and while not able to bring about the

overthrow of the test, they have been bringing about in the minds of all concerned a steadily increasing desire for more exact and better defined specifications. The National Paving Brick Manufacturers Association in 1909 decided to undertake an investigation, with a view to supplying this need. They employed Mr. Marion W. Blair to conduct the investigation for them. Some time after this work was initiated, but before actual testing began, Professor Edward Orton, Jr., came forward with a proposition to cooperate in the proposed investigation by making duplicate studies at his own expense, and by exchange of data with Mr. Blair, to more fully test out the value of all proposed changes in specifications. This offer was accepted by the Association and joint work was begun in April, 1910, and continued into June of 1911. This paper sets forth the results of this study, in part, together with recommendations for a proposed standard method of making the rattler test.

Plan of the Investigation.

The plan decided upon was as follows:

First: To equip both operators with identical machines, made from the same patterns, in the same foundry.

Second: To equip both operators with a large supply of paving bricks from ten different manufacturing plants, these samples to be selected so as to secure a variety in type of product but as much uniformity within each sample as the nature of the product permits.

Third: To make a series of duplicate tests under conditions to be carefully prescribed in advance, with a view to determining what degree of concordance could be obtained with the standard charge of cubic cast-iron shot as prescribed by the old N. B. M. A. tests.

Fourth: To make similar duplicate series using spherical cast-iron shot, and also with no shot, and following in other respects the same procedure before described, with a view to reducing the cost of making the test without decreasing its efficiency.

Beside these comparative studies of the rattler test, there were proposed and carried out certain other studies, such as the difference in quality of bricks representing the different parts of the kiln, the possible use of the absorption test as a mode of grading material for the rattler test, etc., which are not germane to the

subject here under discussion, and to which no further attention will be drawn in this paper. These data will be presented in another paper elsewhere.*

In carrying out the above outline, a carefully prepared set of rules was agreed upon. These rules covered storage, mode of selection of samples, system of designating tests on each sample, number of tests of each kind to be made, mode of conducting the absorption test, selection of charges of bricks from those graded by absorption, condition of rattler (especially the staves), dimensions and quality of shot, mode of rejection of worn-out shot, mode of starting with charges of new shot, quality of iron in the shot, speed and duration of test, stopping and starting, weighing charges, computation of results, and many other minutiæ. The same blank forms for recording all data were also used by both operators.

If all of the above rules had been rigorously observed throughout by both operators, an earlier concurrence would undoubtedly have been obtained. From a lack of appreciation of the importance of exact observance, some differences of procedure did creep in from the beginning, and the most valuable knowledge obtained in the whole study has come from "running down" the discrepancies in the results thus produced, for it has demonstrated the importance of factors not heretofore suspected, and shown how rigid the conditions of the test must be to secure a proper concordance between different operators.

SERIES F.

The first ten letters of the alphabet were agreed upon to represent the ten different brands of bricks to be studied. The first sample to arrive was that designated by the letter F. The quantity was 2,100 bricks, which was equally divided between the two laboratories.

In equipping the two laboratories with cast-iron shot, it was provided that one common lot of each kind of shot, both cubic and spherical, was to be procured and divided. This was done, but with some delay. Prior to the arrival of the shot at Blair's laboratory, he had procured a supply of both cubic and spherical shot from the Over Foundry in Indianapolis, and started his tests.

* Orton—"Some Observations on the Qualities of Paving Brick." *Transactions, American Ceramic Society*, Vol. XIII, p. 792.

Orton, in procuring the shot for distribution, had purchased from two different Columbus foundries. In all cases, both in Indianapolis and Columbus, the same specifications as to hardness of shot, quality of iron, etc., were used and the shot received was supposed by both operators to meet the requirements with sufficient exactness.

Thus, when the testing of Series F began, there were three different lots of shot in use; viz.:—spherical shot made by the H. Loudenslager Foundry Company, of Columbus, used by Orton; cubic shot made by O'Brien Brothers, of Columbus, used by Orton; cubic and spherical shot made by the Over Foundry, of Indianapolis, used by Blair. None of these inequalities were recognized as important, at the beginning.

A slight further inequality in conditions was brought about by Blair using his machines for some preliminary testing on materials for Series H and K, which had come into his possession early, but which had not reached Orton's laboratory. Thus, when Series F was begun, Blair's two machines had made 30 or 40 tests apiece, while Orton's machine was new.

Omitting all needless details, Table I gives a condensed summary of the results of this series. The same data are shown graphically in Fig. 1.

The discussion of the results of Series F will be deferred until the data of Series G have been presented. Owing to failure to cooperate closely enough, the two laboratories were in a different stage of forwardness at the end of Series F, and Series G was tested and available for study at the same time that the Series F data were first exchanged. Up to this point, each laboratory had followed the prearranged schedule according to its own interpretation, and both Series F and G show similar differences in results due to this fact.

SERIES G.

The second material to be distributed jointly between the two laboratories was that predesignated as G. It consisted of 2,100 bricks representing upper, middle and lower sections of the kilns. The only differences between the conditions of the test in Series G and F were those due to the increased wear of the channel steel staves, which were warped and distorted by peening.

TABLE I.—SUMMARY OF RATTLER TESTS UPON BRICKS OF SERIES F.

Position of Bricks in Kiln.		Cubic Shot, 10 Bricks per Charge.		Spherical Shot, 10 Bricks per Charge.		No Shot, 15 Bricks per Charge.	
		Orton, 10 tests.	Blair, 10 tests.	Orton, 10 tests.	Blair, 10 tests.	Orton, 5 tests.	Blair, 5 tests.
Lower Bench..	Average...	16.68	19.89	19.93	17.41	22.68	21.2
	Maximum.	18.80	24.9	22.22	21.3	23.26	22.8
	Minimum..	14.67	17.3	17.74	15.3	22.19	19.0
Middle Bench	Average...	16.10	18.31	19.47	16.35	20.51	20.3
	Maximum.	17.50	20.2	20.81	17.9	21.93	21.0
	Minimum..	14.61	17.3	17.81	14.5	19.00	19.1
Upper Bench..	Average...	18.52	19.35	20.93	17.83	24.19	21.4
	Maximum.	20.40	20.6	23.75	20.5	25.23	22.8
	Minimum..	16.66	18.4	18.28	14.7	22.49	20.2

Conditions of the Tests.—1,800 revolutions at 30 per minute.

Barrel, 28 ins. diameter by 20 ins. long.

Staves, 6-in. steel channels.

Cubic shot charge: 225 lbs. $1\frac{1}{2}$-in. cubes, and 75 lbs. $2\frac{1}{2}$ by $2\frac{1}{2}$ by $4\frac{1}{2}$-in. blocks.

Spherical shot charge: 225 lbs. $1\frac{7}{8}$-in. spheres, and 75 lbs. $3\frac{3}{4}$-in. spheres.

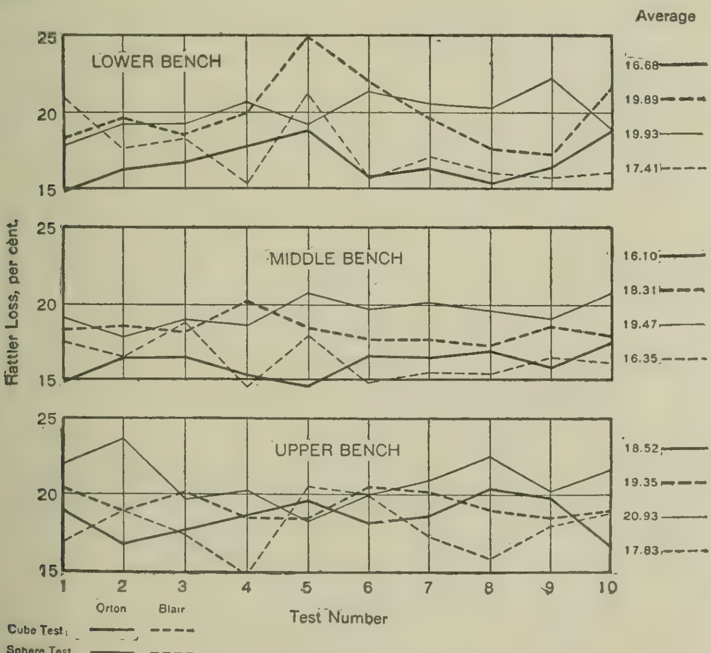

FIG. 1.—Curves of Series F (Partial).

The results of Series G are summarized in Table II and plotted in Fig. 2.

TABLE II.—SUMMARY OF RATTLER TESTS UPON BRICKS OF SERIES G.

Position of Bricks in Kiln.		Cubic Shot, 10 Bricks per Charge.		Spherical Shot, 10 Bricks per Charge.		No Shot, 15 Bricks per Charge.	
		Orton, 10 tests.	Blair, 10 tests.	Orton, 10 tests.	Blair, 10 tests.	Orton, 5 tests.	Blair, 5 tests.
Lower Bench..	Average...	16.94	17.68	20.07	15.42	22.74	21.60
	Maximum.	19.44	19.90	21.69	17.50	23.93	23.10
	Minimum..	15.63	17.00	19.06	13.70	21.88	21.00
Middle Bench.	Average...	17.80	20.32	22.07	18.64	23.69	21.90
	Maximum.	18.83	24.70	29.70	23.20	25.04	24.30
	Minimum..	16.60	17.20	19.71	16.30	22.05	20.80
Upper Bench..	Average...	17.90	18.80	21.94	17.33	24.33	24.70
	Maximum.	20.77	19.40	22.60	18.90	24.45	25.30
	Minimum..	16.72	18.20	21.20	15.60	24.19	24.20

Conditions of the Tests.—Same as in Table I, except those due to distortion of the staves by peening.

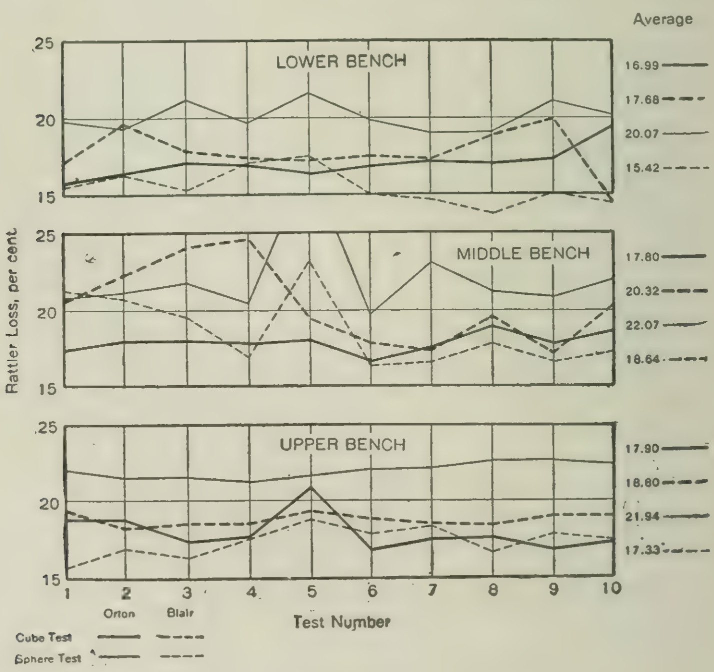

FIG. 2.—Curves of Series G (Partial).

Discussion of the Evidence of Series F and G.—The following points may be noted:

1. The operators do not check each other in any particular in either series, in comparing cube charges against cube charges, or sphere charges against sphere charges.

2. The concurrence in averages in those charges in which no shot is used is much better, though not as good as expected.

3. Orton's results show his cube tests averaging 3 per cent. lower than his sphere tests.

4. Blair's results show his cube tests averaging 2 per cent. higher than his sphere tests.

The radical failure of the two laboratories to check each other, and the curious direct reversal of the relation between cubic shot and spherical shot in the two laboratories, caused a halt in the work until some cause could be ascertained.

The operating conditions were carefully compared. The speed of Blair's machine was often a little less than Orton's, but not enough to cause apprehension at the time. The condition of the rattlers was then discussed. In both laboratories, the channel-iron staves were seriously warped by the peening of the inner surface under the millions of blows. This warpage was worse on Orton's machine, as it did the work alone, while at Blair's laboratory the work was divided between two machines. In Orton's machine, the diameter had been reduced an inch by this warpage and the surface was rendered rough by the edges of the staves warping inwards, so that a better chance was offered for the shot to "climb" in running, and thus fall farther when they went back. At the end of Series G, Orton's machine had made 180 tests and Blair's machines about 127 tests each. A divergence in conditions had thus developed.

Orton now discovered for the first time that Blair was not using the shot which had been sent from Columbus, but was using the "Over" shot which he had had made while waiting for the Columbus shot to arrive. The divergence in conditions thus involved the shot charges as well as the staves, and it was decided to make a fresh start.

Meanwhile, some additional data had been obtained by Orton before the above serious situation had been fully disclosed. This work was upon Series A and E, which had been received

while tests of Series F and G were in progress. This is summarized in Table III:

TABLE III.

PARTIAL RESULTS OF SERIES A, BY ORTON.

Position in Kiln.		Cubic Shot.	Spherical Shot.
Lower Bench	Average (5 tests)	20.76	23.54
	Maximum	22.05	24.14
	Minimum	18.86	22.58
Middle Bench	Average (5 tests)	18.97	21.95
	Maximum	20.42	23.28
	Minimum	18.08	20.92
Upper Bench	Average (5 tests)	19.99	23.40
	Maximum	21.53	25.17
	Minimum	18.36	22.28

PARTIAL RESULTS OF SERIES E, BY ORTON.

Position in Kiln.		Cubic Shot.	Spherical Shot.
Lower Bench	Average (5 tests)	20.15	23.56
	Maximum	21.97	24.63
	Minimum	19.19	22.53
Middle Bench	Average (5 tests)	18.39	21.06
	Maximum	19.64	22.16
	Minimum	17.03	19.18

These results merely still further confirm that, under the procedure and conditions prevailing in the Orton Laboratory, the sphere test gives results averaging 3 per cent. higher than the cube test.

SERIES C.

In order to obtain comparable conditions, one of Blair's machines and Orton's machine were stripped and simultaneously installed with a complete set of new 15.5-lb. medium-steel channel staves, the same as those originally furnished. Blair also rejected the Over shot and put in the Columbus shot charges, both cubic and spherical. A new sample, designated C, was divided between the two laboratories, giving 1,050 bricks from the upper, middle and lower benches, to each laboratory. The results of this comparison are shown in Table IV and are plotted in Fig. 3.

The concordance between the two laboratories is very much better than in any of the preceding work. Cube tests now check cube tests and spherical tests now check spherical tests, but the

TABLE IV.—SUMMARY OF RATTLER TESTS UPON BRICKS OF SERIES C.

Position of Bricks in Kiln.		Cubic Shot, 10 Bricks per Charge.		Spherical Shot, 10 Bricks per Charge.		No Shot, 15 Bricks per Charge.	
		Orton, 10 tests.	Blair, 10 tests.	Orton, 10 tests.	Blair, 10 tests.	Orton, 5 tests.	Blair, 5 tests.
Lower Bench..	Average...	21.71	22.44	22.76	23.40	27.27	24.62
	Maximum.	22.96	25.07	23.81	24.74	27.76	26.64
	Minimum..	20.40	21.76	21.14	22.02	26.17	20.89
Middle Bench.	Average...	23.67	23.83	22.79	24.61	27.45	26.35
	Maximum.	26.11	24.42	24.76	26.22	28.91	27.93
	Minimum..	21.01	22.22	20.71	23.36	26.29	24.23
Upper Bench..	Average...	21.93*	22.18†	22.25*	24.22†	25.74	24.53
	Maximum.	23.78	22.57	23.10	25 05	26.09	24.93
	Minimum..	20.72	21.34	21.59	22.27	25.54	23.85

*Seven tests. †Five tests.

Conditions of the Test.—Same as in Table I, except that each machine was equipped with new staves on starting, and the shot charges were of the same make in both laboratories. The cubic shot, however, were not made by the same foundry as the spherical shot.

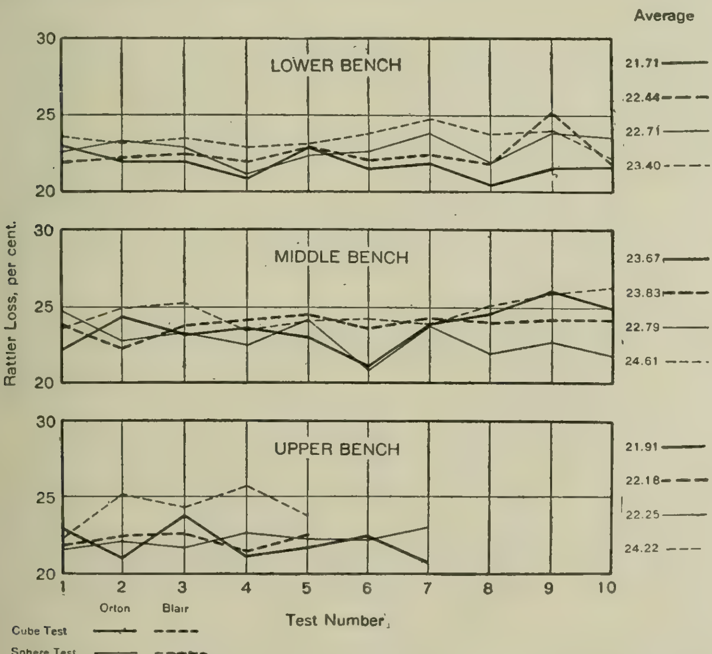

FIG. 3.—Curves of Series C (Partial).

relationship between the cube test and the sphere test has changed. In Orton's data, where the sphere test has heretofore given results 3 per cent. higher than the cubes, we now find it giving but slightly higher losses; while Blair, who heretofore found cubes giving persistently higher losses, now reverses his findings and shows spheres running 1.25 per cent. on the average higher than cubes.

When the investigation had reached this point, it was clear that the shot were in some way connected with our inability to check each other. Blair, therefore, sent these irons to Mr. L. A. Touzalin, Assistant Chief Chemist of the Illinois Steel Company, South Chicago, Ill., and they were carefully analyzed. The results are given in Table V.

Table V.—Analysis of Cast Iron Shot.

Element.	O'Brien Cubes.	Over		Loudenslager Spheres.
		Cubes.	Spheres.	
Combined carbon	0.45	1.46	1.59	2.76
Graphitic carbon	3.02	2.01	1.92	0.41
Silicon	1.73	1.63	1.24	0.96
Sulphur	0.08	0.18	0.18	0.15
Phosphorus	0.68	0.82	0.84	0.53
Manganese	0.51	0.28	0.27	0.27
Scleroscope readings	50.1	60.1	68.7	72.1

The data proved most illuminating. It showed the O'Brien iron to be practically a gray foundry iron, and very soft. The two batches from Over were of medium hard iron, but not nearly as hard as the white Loudenslager iron.

The relation between the hardness of the irons and their wearing power seems clearly indicated. Orton, in five series of tests, aggregating more than 100 comparisons, found spheres of hard white iron giving persistently higher losses than cubes of soft foundry iron. Blair, in two series of tests aggregating 60 comparisons, found spheres of moderately hard iron giving persistently lower results than cubes of the same iron. Blair, in one series of 25 comparisons, with hard spheres and soft cubes, checked Orton's findings, though with reduced differences between the two methods.

The foregoing evidence forced the conclusion that the composition of the metal to be used in the abrasive shot was a matter of critical importance—sufficient to completely overthrow any

probability of making good checks between independent operators, unless using identical shot charges.

It was therefore concluded to abandon, at least temporarily, the scheme which had been originally planned, and take up a more critical investigation into the effects of different kinds of shot.

In order to still further simplify the work, it was desirable to continue the investigation with but one shape of shot. Before deciding which shape to employ, the data thus far obtained were carefully compared.

CUBIC SHOT *vs.* SPHERICAL SHOT.

The spherical shot had proven themselves superior in the following respects:

1. *Ease of Maintenance.*—The cubic shot loses corners and edges very rapidly. In the case of soft and medium foundry irons, the cubes have to be replaced at the rate of about 11 per charge, or 30 to 60 every five tests. This means that the average life of a cube is only 20 to 25 charges. Further, the point of rejection is a matter of some variability, depending upon the judgment of the operator. It is too laborious to accurately weigh each cube after each test, and any visual test involves the judgment as aforesaid. Spheres wear uniformly over their whole surface, from the beginning, and their rate of wear is much smaller than with new cubes. Cubes tend to become spheres by the wear of the rattler.

The relative rates of loss of iron with cubes and spheres of the same make are shown herewith:—

LOSSES IN POUNDS IN PERIODS OF FIVE TESTS.

	"Over" Cubes.	"Over" Spheres.
	9.25	1.35
	13.60	2.50
	7.15	1.10
	7.50	0.90
	7.85	1.30
	7.55	1.60
	6.00	....
Averages......	8.41	1.46

This shows six times as much wear on the cubes as on the spheres. Much more data could be given corroborating the above.

2. *Effectiveness.*—Where spheres and cubes of the same metal are used, so that no factor of variation is introduced except that of shape of the shot, the spheres are found to give lower abrasion losses. Tables VI and VII illustrate this fact.

TABLE VI. ORTON'S LABORATORY.

"LOUDENSLAGER" IRON (SECOND LOT).

BRICK, SERIES D. STAVES, LINED CHANNELS.

	Cubes.	Spheres.
	21.74	20.25
	25.70	21.50
	24.03	22.05
	23.75	19.24
	24.33	22.96
	23.71	22.06
	22.05	21.08
	24.20	21.49
	23.30	22.18
	22.27	21.98
Average.........	23.50	21.47
Maximum........	25.70	22.96
Minimum........	21.74	19.24

TABLE VII.—BLAIR'S LABORATORY.

"OVER" IRON OF MEDIUM HARDNESS.

	Series F (Lower Bench).		Series G (Lower Bench).		Series H (Middle Bench).	
	Cubes.	Spheres.	Cubes.	Spheres.	Cubes.	Spheres.
	18.3	21.0	17.0	15.4	29.9	29.0
	19.6	17.6	19.5	16.3	29.0	28.9
	18.5	18.3	17.9	15.2	33.3	27.9
	19.9	15.3	17.3	17.0	29.1	25.1
	24.9	21.3	17.2	17.5	30.8	26.3
	21.9	15.7	17.5	15.0	....	....
	19 5	17.1	17.3	14.6	....	....
	17.6	16.0	18.7	13.7	....	....
	17.3	15.7	19.9	15.0	....	....
	21.4	16.1	14.5	14.5	....	....
Average..........	19.8	17.4	17.96	15.39	30.4	27.4
Maximum........	24.9	21.3	19.9	17.5	33.3	29.9
Minimum.........	17.3	15.3	14.5	13.7	29.0	25.1

These illustrations are taken at random from a great mass of similar data, and show clearly that where the iron is the same the spheres give a consistently lower figure than the cubes, by about 2 per cent.

3. *Kind of Wear.*—Examination of the bricks tested does not disclose any characteristic differences in the kind of wear. The spheres seem to disclose cavities lying close to the surface of the bricks, just as the cubes do.

On the strength of the marked gain in economy of iron, and the slight difference in the rate of wear of the bricks, the spheres were selected as the basis of all future experiments.

A plan for a careful comparison of the behavior of shot made from different hard irons, with a view to fixing a chemical specification which would insure material of uniform value for this purpose, was now formulated. While the necessary supplies were being secured other work was being carried forward.

INTRODUCTORY WORK ON STAVES.

The stave originally adopted for the joint test was a plain 6-in. medium-steel channel, weighing 15.5 lbs. per linear foot. At the time that the first sets were replaced, as stated in reference to Series C, the peening action of the charge had warped each channel to a marked degree. It was evident that it would be impossible to successfully straighten them. And, as the warpage increased, the results of the test became more erratic and widely divergent, especially in Orton's machine, which was in the worst condition.

It will be recollected that at the beginning of Series C, both Orton's and Blair's machines were equipped with new channel steel staves of the original type.

During the time when Series C was being run, Blair used one of his machines to experiment upon a new set of channel staves lined with $\frac{3}{8}$-in. medium-steel wear-plates fastened to the face of the channel with 3 rivets, countersunk and dressed smooth. The results of the experiment were so encouraging as to justify the equipment of Orton's machine with a similar set of lined channel staves.

With machines in both laboratories equipped with lined channel staves, Series A and E were now carried nearly to completion. The shot used in both laboratories was Loudenslager's hard, white-iron spheres (Lot 1) and O'Brien's soft, gray-iron cubes.

Table VIII gives the summarized data of these two series.

TABLE VIII.—SUMMARY OF RATTLER TESTS, USING LINED STAVES.

BRICKS OF SERIES A (IN PART).

Position of Bricks in Kiln.		Cubic Shot, Soft Gray Iron.		Spherical Shot, Hard White Iron.		No Shot, 15 Bricks per Charge.	
		Orton, 5 tests.	Blair.	Orton, 5 tests.	Blair, 10 tests.	Orton, 5 tests.	Blair, 5 tests.
Lower Bench..	Average...	18.07	No data obtained.	20.97	20.34	25.12	23.57
	Maximum.	18.57		22.69	22.05	26.21	25.67
	Minimum..	16.87		20.08	18.33	22.98	22.29
Middle Bench.	Average...	16.65		18.12	19.14	23.25	21.73
	Maximum.	18.71		19.15	20.11	24.84	22.90
	Minimum..	15.24		17.22	17.15	21.58	20.00
Upper Bench..	Average...	18.26		18.48	19.84	22.26	21.28
	Maximum.	20.68		19.28	22.05	23.55	23.27
	Minimum..	16.20		17.03	17.42	21.88	20.27

BRICKS OF SERIES E (IN PART).

Position of Bricks in Kiln.		Cubic Shot, Orton	Cubic Shot, Blair	Spherical Shot, Orton	Spherical Shot, Blair	No Shot, Orton	No Shot, Blair
Lower Bench..	Average...	18.01	17.71	20.85	18.23*	25.72	21.78
	Maximum.	18.73	19.07	22.70	19.66	26.66	22.66
	Minimum..	16.55	16.99	20.15	17.00	24.78	21.03
Middle Bench.	Average...	16.61	15.63	18.49	17.25*	23.15	20.87
	Maximum.	17.36	16.04	19.31	18.23	23.51	21.30
	Minimum..	15.36	15.21	16.84	15.60	22.74	20.44
Upper Bench..	Average...	16.52	17.06	17.26	17.36*	21.26	21.35
	Maximum.	17.45	17.77	17.72	18.01	22.65	21.89
	Minimum..	15.33	16.00	16.11	16.80	19.83	20.32

The salient points to be noted in Table VIII are as follows:

1. Both operators agree fairly well on both cube *vs.* cubes, and sphere *vs.* spheres.

2. As between cubes and spheres, the data merely serve as a check on Series C, since the newly planned shot were not yet available and the old spheres and cubes were still being used. The hard spheres were inflicting from 1.5 to 1.75 per cent. greater loss than the soft cubes, on the average, and the quality of the iron is thus again seen to overweigh the difference in the shape of the shot.

Examining now the influence of the new lined staves and the old un-lined staves, the comparison in Table IX can be compiled from Orton's data. It is shown graphically in Fig. 4.

* Average of 5 tests, instead of 10 as in column above.

TABLE IX.—TESTS WITH LINED AND UN-LINED STAVES.

Comparisons on Five Tests Each.

SERIES A.

Position of Bricks in Kiln.		Old Staves. (Badly warped and rough.)	New Staves, Lined. (Smooth.)
Lower Bench	Cubes	20.76	18.07
	Spheres	23.54	20.97
Middle Bench	Cubes	18.97	16.65
	Spheres	21.95	18.12
Upper Bench	Cubes	19.99	18.26
	Spheres	23.40	18.48

SERIES E.

Lower Bench	Cubes	20.15	18.01
	Spheres	23.56	20.85
Middle Bench	Cubes	18.39	16.61
	Spheres	21.06	18.49

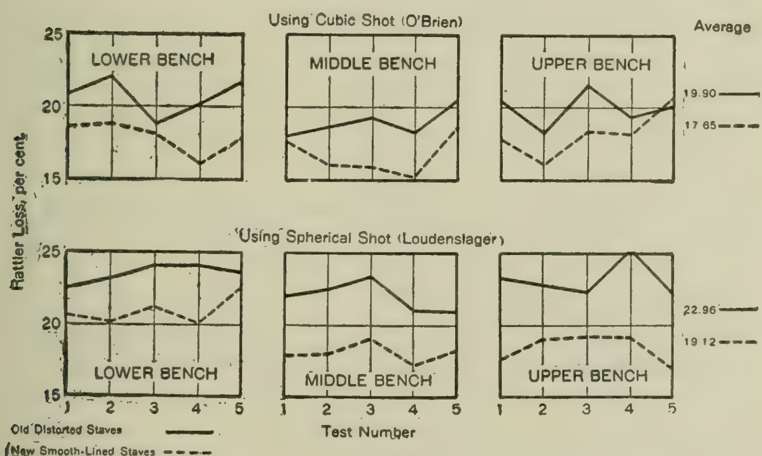

FIG. 4.—Influence of Condition of Staves on Rattler Losses. Series A (Orton's Results).

The rough interior of the barrel, affording better opportunity for the shot to climb, and thus fall farther, and also for bricks to strike against rough edges of staves, is thus seen to occasion an increased loss of 2.8 per cent. on the average.

At the end of this work the lined stave was still in excellent condition and presented only very slight convexities between rivets, due to peening.

THE CHICAGO OR "NO SHOT" TEST.

The data obtained by this process have been shown in their place in all of the tables thus far, but little attention has been given to them in the discussions. At this point the evidence was reviewed, to decide whether or not to continue this test.

For convenience, the averages of the "Chicago tests" of each series are assembled in Table X.

TABLE X.—"CHICAGO TEST" COMPARISONS.

Bench.	Orton. Averages of 5 tests.	Orton. General Average (15 tests).	Blair. Averages of 5 tests.	Blair. General Average (15 tests).	Remarks.
SERIES F.					
Lower....	22.68		21.20		Staves warped; interior of barrel rough.
Middle....	20.51	22.46	22.80	21.0	
Upper....	24.19		19.00		
SERIES G.					
Lower....	22.74		21.60		Staves very badly warped; interior of barrel very rough.
Middle....	23.69	23.58	21.90	22.73	
Upper....	24.33		24.70		
SERIES C.					
Lower....	27.27		24.62		Staves new; interior of barrel smooth.
Middle....	27.45	26.82	26.35	25.16	
Upper....	25.74		24.53		
SERIES A.					
Lower....	25.12		23.57		Staves lined; interior of barrel smooth.
Middle....	23.25	23.67	21.73	22.19	
Upper....	22.66		21.28		
SERIES E.					
Lower....	25.72		21.78		Staves lined; interior of barrel smooth.
Middle....	23.15	23.37	20.87	21.33	
Upper....	21.2[illegible]		21.35		

The foregoing data show the following points:

1. The results in Blair's laboratory average 1.25 per cent. lower than in Orton's. The same fact can be found in the shot tests up to this point, and later in this report in the tentative standard series. The explanation arrived at is a difference of speed, being below the proper limit in Blair's machine. This difference was slight in the beginning, but became more important as the tests progressed, as shown later.

2. The tests run higher in actual losses than in the corresponding shot tests. Selecting for comparison the tests executed with Loudenslager spherical shot (first lot) we have the values shown in Table XI.

TABLE XI.—COMPARISON BETWEEN GENERAL RESULTS OF NO SHOT AND SPHERICAL SHOT TESTS.

Series.	No Shot.		Spherical Shot.	
	Orton's Averages.	Blair's Averages.	Orton's Averages.	Blair's Averages.
F.........	22.46	21.00	20.51	.....
G.........	23.58	22.73	21.16	.....
C.........	26.82	25.16	22.64	23.89
A.........	23.67	22.19	19.19	19.80
E.........	23.37	21.33	18.87	17.61

These figures are in nearly all cases the average of 15 charges each. The early sphere tests by Orton on Series A and E were excluded from the comparison on account of condition of staves. The sphere-test averages given for Series A and E are from the tests made when the staves had been lined. The corresponding all-brick charges were run at the same time and hence are comparable. The table shows a difference between the two methods amounting to about $3\frac{1}{2}$ per cent. on the averages.

3. The same characteristic tendencies are shown in the various materials when tested by either of the two methods. Fig. 5 is a plot of the data given in Table XI.

From the foregoing, it may well be questioned why the shot test should not be abandoned and the simpler and cheaper all-brick test be revived.

So far as the evidence we have secured in this work is concerned, there is no reason why such a change might not be made.

But, at the time that the old all-brick test was abandoned in favor of the shot test, it was demonstrated by Talbot and others that the shot charges had superior selective wear, where hard and soft bricks occurred in the same charge. In those days, when material was not as uniformly hard as it is at present, the importance of continually watching for soft bricks was keenly felt, and it is not at all sure that this necessity does not still exist in many localities.

For this reason it was thought best not to recommend the change from the shot test, unless a more searching inquiry is made to demonstrate fully the relative selective capacity of the two methods. The present work, while interesting, was always per-

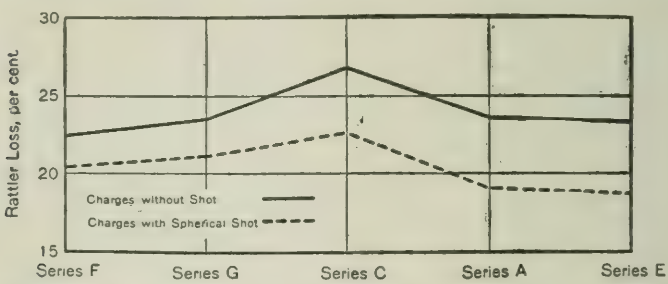

FIG. 5.—Comparison between Average Abrasion Losses of Charges without Shot and with Spherical Shot (Orton's Results).

formed on hard brick of rather uniform quality, and hence does not afford a good chance to study the whole problem.

THE RELATIVE PERFORMANCE OF SPHERICAL SHOT CHARGES MADE FROM DIFFERENT VARIETIES OF HARD IRON.

Three manufacturers, all represented to be able to furnish a homogeneous and uniform grade of very hard white iron, were employed to prepare batches of spherical shot of the two sizes. Each manufacturer was to furnish two separate batches, separating the first order from the second by a time interval of several weeks, in order to see whether the quality furnished by the same plant in consecutive shipments would vary much. There was great delay in getting these various lots and dividing them between the two laboratories, and of one variety of shot but one batch was ever secured.

With these various lots of hard-iron spherical shot, a series of tests was made upon a new lot of bricks, Series D. A shipment of 3,000 of this brand was obtained and divided equally between the laboratories. The shipment was a commercial one, and not selected for testing purposes as the previous lots had been. It therefore showed a somewhat greater variation within itself than some of the others.

Table XII gives the data obtained in making this shot comparison.

The Loudenslager Shot.—The physical character of this shot was poor. While fairly accurate in weight, they were very frequently full of blow-holes or dimpled with sink-holes, due to contraction in cooling. They were brittle, easily crushed with a heavy hammer, and occasionally broke in the rattler.

The analyses of the two lots of the Loudenslager shot are as follows:

	Lot 1.	Lot 2.
Combined Carbon	2.76 per cent.	1.48 per cent.
Graphitic Carbon	0.41 " "	1.47 " "
Silicon	0.96 " "	1.66 " "
Manganese	0.27 " "	0.18 " "
Phosphorus	0.53 " "	0.72 " "
Sulphur	0.15 " "	0.20 " "

The average results (10 tests each) given by these two lots of shot, all other things being equal, were:

	Lot 1.	Lot 2.
Orton	23.37	21.47
Blair	21.86	20.15

The second lot of shot varied widely in character from the first and gave distinctly lower wearing power in the rattler. The maximum and minimum figures are also lower in the second series, showing that it is not accidental. The lower results obtained with the second lot are exactly in line with the facts disclosed in Series F and G, where the Loudenslager shot (first lot) was compared with the Over shot from Indianapolis, whose composition was very similar to that of the second lot of Loudenslager shot.

The wide divergence in chemical composition in the Loudenslager material was deemed by us a sufficient reason for giving it no further consideration as a possible future standard material.

TABLE XII.—COMPARISON OF WORK OF DIFFERENT SPHERICAL SHOTS OF HARD IRONS.

H. LOUDENSLAGER FOUNDRY COMPANY, COLUMBUS, O.

	Lot 1.		Lot 2.	
	Orton.	Blair.	Orton.	Blair.
	21.06	21.25	20.25	17.94
	23.06	22.68	21.50	20.34
	20.96	20.91	22.05	18.70
	24.31	23.17	19.24	20.41
	23.63	22.95	22.96	20.14
	24.60	20.71	22.06	20.64
	23.37	21.14	21.08	20.49
	22.58	22.85	21.49	23.37
	26.41	21.87	22.18	19.03
	23.63	21.16	21.98	20.50
Average...	23.37	21.86	21.47	20.15
Maximum.	26.41	23.17	22.96	23.37
Minimum..	20.96	20.71	19.24	17.94

NATIONAL MALLEABLE CASTINGS COMPANY, INDIANAPOLIS, IND.

	21.78	20.50	24.25	21.39
	22.71	21.86	23.24	20.91
	21.47	20.61	21.78	22.57
	22.36	21.75	23.20	21.76
	21.31	20.86	24.40	21.20
	21.91	21.69	23.44	20.52
	20.95	21.99	24.29	21.22
	21.88	20.25	24.72	23.47
	20.79	21.08	22.12	22.14
	19.57	20.27	24.60	20.31
Average...	21.47	21.08	23.60	21.54
Maximum.	22.71	21.99	24.72	23.47
Minimum..	19.56	20.25	21.78	20.31

AMERICAN CAR AND FOUNDRY COMPANY, ST. LOUIS, MO.

	21.47	19.68	Not furnished.	
	21.70	21.41		
	22.58	19.45		
	21.94	19.11		
	24.43	20.85		
	21.47	18.43		
	24.00	19.90		
	21.80	21.04		
	22.61	20.53		
	24.07	.....		
Average...	22.60	20.04		
Maximum.	24.43	21.41		
Minimum..	21.47	18.43		

We had believed that its process of manufacture and the quality of materials would automatically, or by the self-interest of the maker, operate to keep its constitution and hardness about uniform, but the above demonstrates that this view was incorrect.

The American Car and Foundry Company Shot.—The physical character of this shot was a little better than the preceding, but not much. It was roughly cast and had some blow-holes, but was tough. None of it broke in the rattler. It cost more than twice as much as the preceding, but with little real gain in quality. Its uniformity is unknown, as no second batch was secured.

The analysis, and that of Loudenslager No. 1 for comparison, are given below.

	American Car and Foundry Company.	Loudenslager. (Lot 1.)
Combined carbon...	2.72 per cent.	2.76 per cent.
Graphitic carbon...	0.89 " "	0.41 " "
Silicon............	0.53 " "	0.96 " "
Manganese.........	0.31 " "	0.27 " "
Phosphorus........	0.109 " "	0.53 " "
Sulphur...........	0.179 " "	0.15 " "

The average results (10 tests each) given by these two lots of shot, were:

	American Car and Foundry Company.	Loudenslager. (Lot 1.)
Orton.............	22.60	23.37
Blair..............	20.04	21.86

The influence of the increased proportion of graphite in the American Car and Foundry Company shot is apparent, even where the combined carbon is so closely similar.

The National Malleable Castings Company Shot.—The physical character of this material was excellent. It was beautifully smooth and regular, free from blow-holes, very tough, and absolutely unbreakable with a sledge. The chemical composition of every heat from which spheres were cast was obtained from the heat-book of the company and was exceedingly regular. The metal was not a cupola-melted cast iron. It was melted in an air-furnace, and held there, subject to chemical influences which gradually converted its carbon wholly into the combined condition. It was tapped out and cast only when test showed it to be

converted to this new condition. It was not, therefore, properly comparable with an ordinary cast iron shot, though obtainable at about the same price. Table XIII gives the analyses of the two lots.

TABLE XIII.

	Lot 1.			Lot 2.		
	Average of 22 Analyses.	Maximum.	Minimum.	Average of 10 Analyses.	Maximum.	Minimum.
Combined carbon	2.74	2.96	2.51	2.88	3.21	2.75
Graphitic carbon	....	....	....	....	....	....
Silicon	0.82	1.00	0.70	0.78	0.92	0.67
Manganese	0.26	0.30	0.19	0.23	0.26	0.20
Phosphorus.....	0.17	0.18	0.15	0.19	0.25	0.15
Sulphur........	0.051	0.07	0.03	0.05	0.05	0.04

The results of the rattler test (average of 10 tests each) conducted with this shot are:

	Lot 1.	Lot 2.
Orton..............	21.47	23.60
Blair	21.08	21.54

The remarkable uniformity of the above material and its physical perfection constitute a strong endorsement for the use of shot produced by this process of manufacture.

Influence of Combined vs. Graphitic Carbon.—A study of the above data seems to point to the conclusion that the graphite is associated with the diversified wearing power of different irons. The data of Table XIV lend color to this view.

TABLE XIV.

Combined Carbon.	Graphitic Carbon.	Averages of 10 Tests Each.	
		Orton.	Blair.
2.88	trace	23.60	21.54
2.74	trace	21.54	21.08
2.76	0.41	23.37	21.86
2.72	0.89	22.60	20.04
1.48	1.47	21.47	20.15

A similar effect can also be observed in comparing graphitic cast-iron staves and hard white-iron staves. The effect of the

graphite probably is that of slight lubrication, promoting flow and decreasing opportunity for "climbing" of the shot, which reduces impact. A small piece of soap introduced into a rattler exercises a very pronounced similar effect.

For the above reasons, it is believed that the air-furnace iron, devoid of all but traces of graphitic carbon, offers far the greatest chance of uniformity of any kind of iron attainable.

Influence of Silicon.—Silicon is known to strongly affect the brittleness of cast iron. It does not affect the hardness of the metal itself, at least not within the limits considered in the present connection. Cast iron high in silicon would be more likely to crush in the rattler. Air-furnace iron is more likely to be low in this substance than cupola-melted iron.

Manganese.—Manganese lends toughness, if the quantity be high, but it is not feasible to secure cast iron high in manganese except by making it to order and at great cost.

Phosphorus and Sulphur.—Phosphorus makes "cold short" or brittle cast iron. Sulphur makes "hot short" steel—its effect on cast iron is probably in the direction of brittleness.

Table XV gives a comparison of the relative behavior of the iron constituents of the charges mentioned above.

TABLE XV.—LOSSES IN WEIGHT (IN POUNDS) OF CHARGES OF IRON SPHERES; (300 LBS.) IN PERIODS OF FIVE RATTLINGS EACH.

Period.	Loudenslager Spheres.		National Malleable Casting Company's Spheres.
	Lot 1.	Lot 2.	Lot 1.
1	2.06	1.57	0.87
2	3.00	2.45	0.37
3	1.75	1.76	0.57
4	1.25	....	0.62
5	1.75	....	0.63
6	....	....	0.56
7	....	....	0.93
Averages...........	1.96	1.93	0.65

The greater brittleness of the Loudenslager material, due to its higher silicon phosphorus and sulphur, is strongly shown in the relative losses in weight of iron. Many crushed and broken Loudenslager spheres were found in the rattler and removed from

time to time, but never one of the National Malleable Company's make. The presence of 0.41 per cent. of graphite in the former is not able to offset the effect of the above-mentioned ingredients.

THE RELATIVE PERFORMANCE OF DIFFERENT TYPES OF STAVES.

The work on Series A and E showed clearly that the lined channel stave was a very great improvement over the plain one. Because of its compound structure, it was thought proper to subject it to a searching comparison with other types of simple, single-piece staves, before deciding on its adoption.

There had been some researches made at Chicago and Cleveland on the stave question, and although these results were unpublished we were informed that they indicated that differences in the thickness, rigidity and hardness of the staves influenced the results very markedly. Hence, it was decided to procure a series of different staves and test them out in a competitive way, by running ten tests in each laboratory as follows:—

1. Lined channel staves, as described.
2. Steel plates, ¼ in. thick.
3. Steel plates, ½ in. thick.
4. Steel plates, ¾ in. thick.
5. Manganese steel plates, ¾ in. thick.
6. Soft cast iron plates, ¾ in. thick.
7. Hard white cast iron plates, ¾ in. thick.

The manganese steel staves and both hard and soft cast iron staves were made from the same drawing, but different patterns were prepared in each case. In making these stave tests the Loudenslager spheres (Lot 1) were used exclusively by both operators. The comparison was run upon Series D material, the same as that used for the shot tests just discussed. Table XVI gives the data obtained.

Analysis of the Data of the Stave Test.—The theory upon which the stave investigation was begun was that the rigidity or springiness of the stave was a matter of profound concern. This idea has been somewhat urgently advocated as the result of tests made in Chicago a year or two ago. Studying the results of our series, the data in Table XVII may be marshalled.

TABLE XVI.—SHOWING RELATIVE PERFORMANCE OF DIFFERENT TYPES OF STAVES.

	Lined Channels.		½-in. Steel Plate Staves.		⅓-in. Steel Plate Staves.		¼-in. Steel Plate.	
	Orton.	Blair.	Orton.	Blair.	Orton.	Blair.	Orton.	Blair.
	21.06	21.25	21.40	23.72	20.49	21.52	20.45	20.32
	23.06	22.68	22.28	22.65	22.35	22.53	21.72	18.42
	20.96	20.91	21.21	24.57	22.13	21.26	22.61	20.72
	24.31	23.17	21.57	23.33	22.02	22.52	22.47	21.38
	23.63	22.95	22.61	23.24	22.87	21.25	25.12	22.02
	24.60	20.71	23.87	21.69	22.22	20.98	20.49	19.84
	23.37	21.14	22.05	24.46	20.86	21.83	22.06	21.37
	22.58	22.85	23.01	25.25	21.54	20.76	25.12	22.60
	26.41	21.87	25.64	22.54	22.16	20.76	22.48	19.63
	23.63	21.16	23.30	23.55	23.08	22.66	22.43	21.66
Average	23.37	21.86	22.59	23.50	21.97	21.60	22.49	20.796
Maximum	26.41	23.17	25.64	25.25	23.08	22.53	25.12	22.60
Minimum	20.96	20.71	21.21	21.69	20.49	20.76	20.45	18.42

	Manganese Steel Plate.		Cast Iron (Soft Gray).		Cast Iron (Hard White).	
	Orton.	Blair.	Orton.	Blair.	Orton.	Blair.
	20.37	21.00	19.39	20.26	20.61	Not Tested.
	21.23	21.50	19.43	19.18	20.13	
	20.78	20.56	19.47	17.09	21.93	
	21.81	19.71	20.64	21.39	21.55	
	23.44	20.28	21.13	20.37	20.43	
	20.21	20.87	21.41	20.02	20.00	
	21.15	19.54	17.69	19.56	20.05	
	20.97	21.70	21.24	20.04	21.25	
	20.55	22.14	19.65	19.57	20.84	
	20.76	21.61	19.62	18.12	19.73	
Average	21.12	20.79	19.96	19.56	20.65	
Maximum	23.44	22.14	21.41	21.39	21.93	
Minimum	20.21	19.54	17.69	17.09	19.73	

TABLE XVII.

Variety of Stave.	Orton's Results, 10 tests.	Blair's Results, 10 tests.	Combined Results, 20 tests.
¼-in. steel plate (medium soft)	22.59	23.50	23.04
½-in. " " " ")	{21.97 21.36}	21.60	21.78
¾-in. " " " ")	22.49	20.79	21.64
15.5-lb. 6-in., medium steel channel, lined with ⅜-in. medium steel wear plates	23.37	21.86	22.61
3-in. cast slaves (manganese steel, intensely hard and rigid)	21.12	20.79	20.95
¾-in. cast slaves (soft machinery iron)	19.96	19.56	19.76
¾-in. " " (hard white iron)	20.65	.....	.....

1. Comparison of the data for the first four staves, all of which are made of medium steel, and which are arranged in order of rigidity, does not lend strength to the foregoing view. The fluctuations seem erratic and not greater than the variability of the material tested might easily explain.

2. A second idea in the stave test was that hard surfaces would react upon an impinging brick differently from a soft or slippery graphitic surface. The known superiority of the special steels made for abrasion and grinding machinery, led us to try the use of a manganese steel stave. This material is not only intensely hard, but also very tough and may be bent considerably before breaking. The comparison of the data in the last four sets of staves—soft steel, hard steel, soft cast-iron, hard cast-iron—shows:

(*a*) That the hard staves, both cast-steel and cast-iron, show less losses than the soft-steel staves.

(*b*) That the soft cast-iron stave shows smaller losses than any other kind of stave.

These data, while not conclusive, or indicating that the material of which the staves are made is of vital importance, do still seem to show that the metal of which the stave is made has some slight effect on the results. It was considered to be sufficient to justify the exclusion of a choice of stave material and warrant the specification of one material only as the standard equipment.

3. The third point developed by this study is that the form, or the ability to retain its original form, is more important than anything else. The early tests of Series F, G, A, and E, all showed conclusively that as the staves became distorted by peening, they created a rough interior to the barrel and thus changed the

conditions, and made the results more erratic, and increased the actual rate of wear by 2 per cent. or more. This is very clearly shown in Table IX.

The data show that while the thin (and therefore springy) steel-plate staves are not inherently worse than others when new, they are not to be recommended because they peen rapidly and become distorted so soon. If used at all, they would require very frequent straightening, which is costly and likely to be neglected.

The recommendation in favor of the channel steel stave is its superior rigidity compared to a flat steel plate. But the work of Series F and G and parts of Series A and E show clearly that it is still too easily distorted to be a good investment, and also, when distorted, it is practically out of the question to straighten it again, while a flat plate can be straightened by any blacksmith.

The use of a face-plate to take up the peening and wear, and permit the channel stave to furnish the permanent support for it, has proved a very satisfactory step. The distortion of the unlined channel staves was so bad after 150 tests that they were continually stripping off heads of bolts, or tearing out bolt holes. Five boxes of bolts were used in repairs on one machine in about 200 tests. The lined channel stave completely avoids this difficulty since it remains rigidly in position; its bolts seldom work loose and never pull in two, or strip. The wear plate, on the other hand, being riveted firmly in its place at three points on its center line, and free to expand in most all directions under the peening action of the shot, is under no great stress, and while it will occasionally work loose and require re-riveting, this repair can be done easily and quickly by any ordinary mechanic or testing-machine operator. The peening action causes the wear plate to buckle up between rivets, presenting a slightly convex surface and fitting down tightly on the channel around the edges of the plate. This convexity does not exceed $\frac{1}{2}$ in. in height after 150 tests. The cost of relining the channel is not great and thus the staves can easily be kept in good condition.

RESUMPTION OF THE ORIGINAL COMPARISONS.

The completion of the foregoing work now brought us to a point where the original plan could be resumed: that is, to determine what degree of concordance could be obtained between two

TABLE XVIII.—COMPARISONS BY THE REVISED METHOD OF TESTING.

	Series A. (Middle Bench Only.)		Series C.		Series D.		Series E. (6 from Middle Bench and 4 from Lower Bench.)		Series F. (4 Top, 3 Middle, 3 Lower.)	
	Orton.	Blair.	Orton.	Blair.	Orton.	Blair.	Orton.	Blair.	Orton.	Blair.
	18.78	19.22	23.80	23.78	21.78	20.50	18.55	18.08	17.51	16.16
	20.06	18.96	24.44	23.82	22.71	21.86	18.23	19.89	18.44	16.06
	20.24	18.29	23.95	24.11	21.47	20.61	20.09	16.81	18.75	15.42
	18.72	17.83	24.97	23.84	22.36	21.75	18.08	17.89	18.63	17.25
	19.47	19.65	24.49	23.09	21.31	20.86	19.02	18.20	17.99	16.80
	19.26	18.94	.....	.....	21.91	21.69	18.83	19.03	17.30	19.72
	18.96	17.24	.....	.....	20.95	21.99	19.60	17.82	17.48	17.49
	19.89	18.88	.....	.....	21.88	20.25	20.54	15.69	19.51	15.38
	20.38	19.54	.....	.....	20.79	21.08	20.87	16.82	18.70	17.86
	20.12	19.77	.....	.....	19.56	20.27	19.37	17.84	17.74	14.44
Average...	19.59	18.83	24.33	23.72	21.47	21.08	19.31	17.80	18.20	16.95
Maximum.	20.38	19.77	24.49	24.11	22.71	21.99	20.87	19.89	19.51	19.72
Minimum..	18.72	17.24	23.80	23.09	19.56	20.25	18.08	15.69	17.30	14.44

	Series G. (4 Top and 6 Middle.)		Series H. (All Middle Bench.)		Series K.		Series M.		Series P.	
	Orton.	Blair.	Orton.	Blair.	Orton.	Blair.	Orton.	Blair.	Orton.	Blair.
	19.14	16.35	25.67	27.20	20.30	16.40	18.41	21.03	16.40	15.34
	17.90	15.50	30.47	25.59	18.42	17.42	18.08	17.59	16.46	16.43
	18.45	17.68	30.23	28.87	17.68	17.41	20.36	19.26	16.81	16.95
	18.24	17.27	25.66	24.41	19.42	16.49	18.40	18.62	17.40	17.70
	18.60	17.35	29.76	26.03	18.97	18.54	18.78	17.97	16.84	.....
	19.38	16.54	23.33	27.76	17.59	17.56	19.64	21.99	.....	.....
	18.53	17.11	25.07	24.59	20.23	17.20	17.24	16.94	.....	.....
	19.35	16.22	28.34	25 07	18.57	18.04	19.25	19.67	.....	.....
	19.13	16.37	29.44	27.26	18.46	18.23	18.38	17.91	.....	.....
	18.81	17.58	30.25	25.65	19.63	18.37	20.20	21.65	.....	.....
Average...	18.77	17.39	27.82	26.24	18.92	17.56	19.07	19.25	16.78	16.60
Maximum.	19.58	17.68	30.47	27.76	20.30	18.54	20.37	21.65	17.40	17.70
Minimum..	17.90	15.50	23.33	24.41	17.59	16.40	17.24	16.94	16.40	15.34

operators when testing the same brick and following the same specifications. Irregularities due to variation in the quality of the shot and the kind and condition of the staves, which had not previously been known, could now be provided for. The other variable factors in the rattler test, such as rate of rotation, duration of rotation, number of bricks per charge, etc., having been covered in the old specifications and in use for ten years, had been rather well determined, and no developments in this investigation had given any reasons to suggest their overthrow.

For the new comparisons, the following plan was made:

First: To secure twenty charges of ten bricks each from ten different manufacturers of paving bricks—a total of 200 charges.

Second: These were to be divided equally between the two laboratories to be tested by the new plan.

Third: The samples to be selected were to be taken as far as

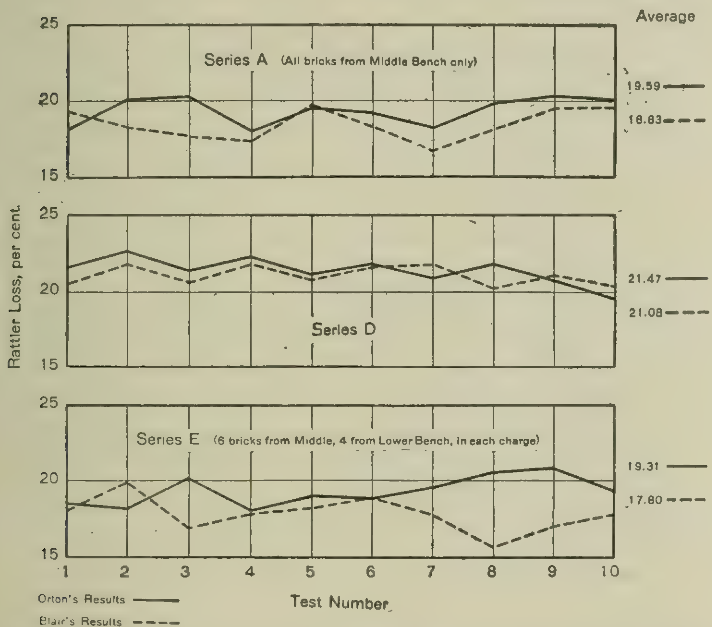

FIG. 6.—Degree of Concurrence attained with Improved Spherical Shot and Lined Steel Staves.

possible from the remainder of the large car-load samples used in Series A, C, D, E, F and G. The other four samples were to be secured direct from the manufacturers and were to represent what they considered to be first-class material—perhaps not their best, but certainly well above the average in uniformity and exterior excellence. Of the six samples taken from the old series, there were not enough bricks available from a single bench of the kiln to make the requisite 20 charges of each brand.

In this case, charges were compounded from two or even three benches. When this was done, each charge was made to contain the same number of bricks from the several benches as every other charge in the same series, thus making the charges strictly comparable.

Fourth: The method of testing was as follows:

(a) The shot charge should consist of ten $3\frac{3}{4}$-in. spheres,

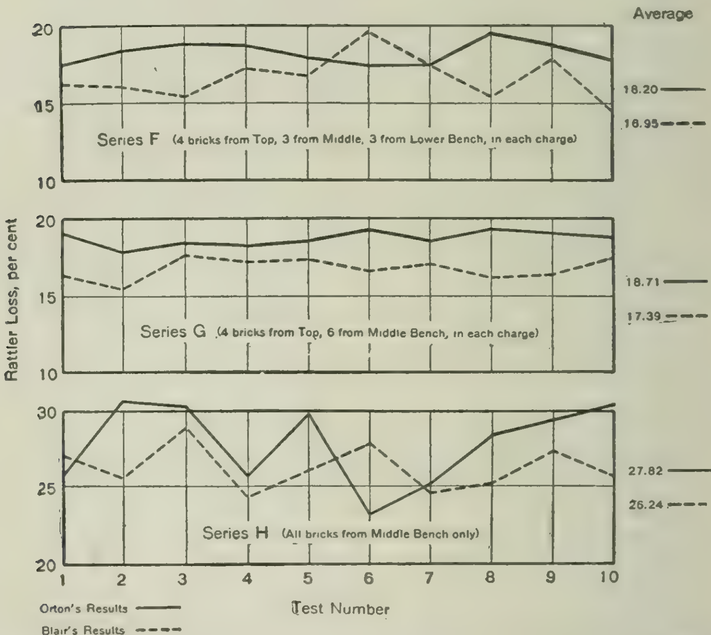

FIG. 7.—Degree of Concurrence attained with Improved Spherical Shot and Lined Steel Staves.

weighing as nearly as possible 75 lbs., and as many $1\frac{7}{8}$-in. spheres made by the National Malleable Castings Company, the properties of which have been discussed, as would bring the combined weight to 300 lbs.

(b) The lined channel steel staves were to be used and relined whenever peened to a serious extent, and in no case to be run more than 150 tests without renewal.

(*c*) Other conditions were to remain the same as in the original procedure.

The results of these comparisons are given in Table XVIII, and are plotted in Figs. 6, 7 and 8.

The study of the foregoing shows that Orton's averages are regularly higher than Blair's. The amounts are not large: +0.76, 0.61, 0.39, 1.51, 1.25, 1.36, 1.58, 1.36, 0.18, and one −0.18. The

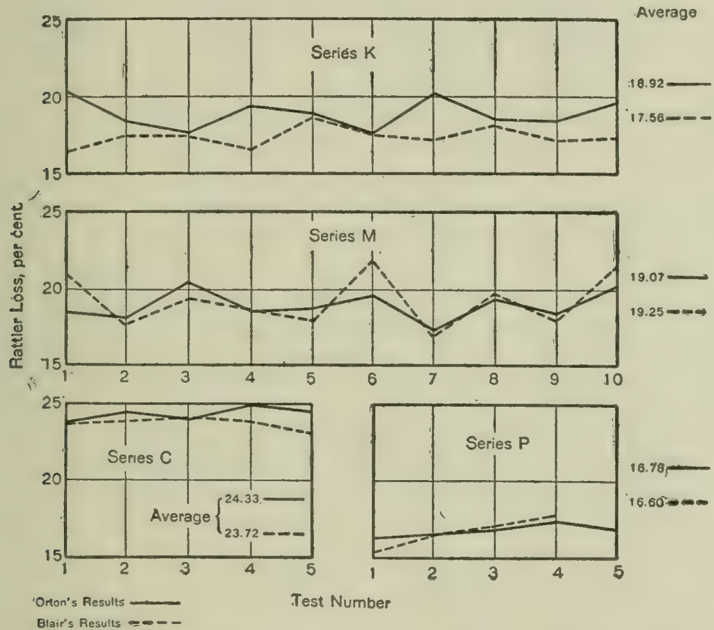

FIG. 8.—Degree of Concurrence attained with Improved Spherical Shot and Lined Steel Staves.

average of these amounts is +0.88, Orton over Blair. If the sign of these differences was not practically one way they would be construed as satisfactory checks. But, since they point persistently in one direction, there must be a reason for it.

Influence of Speed of Rotation.—The data of each observer was again searched and a difference in speed was found, which had been noted earlier in the joint work and which was trifling at that time,

TABLE XIX.—COMPARISON OF RATTLER LOSSES AND SPEED OF REVOLUTION.

	Orton.		Blair.	
	Rattler Losses.	Average Speed, R. P. M.	Rattler Losses.	Average Speed, R. P. M.
	18.55	30.12	18.08	29.75
	18.23	29.71	19.89	29.50
	20.09	29.62	16.81	27.75
	18.08	29.71	17.89	28.33
	19.02	29.75	18.20	27.69
	18.83	30.17	19.03	30.10
	19.60	30.04	17.82	29.38
	20.54	30.34	15.69	27.75
	20.87	30.25	16.82	28.57
	19.37	30.42	17.84	28.33
Average...	19.31	30.01	17.80	28.71

but which had now become much more considerable. Table XIX from Series E, which shows about the highest average discrepancy between Orton and Blair, was selected to illustrate this point.

There would seem to be but little doubt that these low speeds on Blair's machine during the winter months of 1910–11 were responsible in whole or in part for the persistently low results which he secured.

In order to obtain a final comparison, in a laboratory in which this speed factor could be corrected, arrangements were made for Blair to use a newly installed machine in the Laboratory of the

TABLE XX.—COMPARISON, SERIES F (SECOND), UNDER CONTROLLED SPEED CONDITIONS.

	Orton.			Blair.		
	Loss.	R.P.M.	Remarks.	Loss.	R.P.M.	Remarks.
	17.25	30.04	Lining was near its point of rejection; viz., 128–133 tests. It was warped and peened considerably.	15.78	30.00	Lining was new and in good order; only 3 or 4 tests had been run on it.
	16.94	30.08		15.24	29.84	
	19.27	30.08		16.59	29.75	
	17.55	30.04		19.13	29.71	
	18.92	30.04		17.03	29.71	
	16.55	30.22	New lining was installed complete and these five tests run upon it without preliminary wear.	18.56	29.75	
	15.86	30.25		16.20	29.75	
	15.44	29.96		14.58	29.99	
	15.65	29.75		16.04	29.79	
	18.46	29.96		14.59	29.71	
Average.	17.19	30.04		16.37	29.80	

Ohio State Highway Commission. This machine was a duplicate of that used in the rest of this study. The bricks were 200 in number taken from a commercial shipment standing upon the street ready for laying. Each operator received 100 and made 10 tests. The results are given in Table XX.

The last five tests made by Orton in the above table, and the entire ten by Blair are about as closely comparable as can be obtained. The first five tests by Orton were made with the lining about ready for rejection, which may or may not have affected the results.

There are too few data available to prove with certainty that low speed was the cause of Blair's results running lower than Orton's in the final ten comparisons, but this presumption has been somewhat strengthened by the above test.

CONCLUSIONS.

1. Spherical shot, of the quality used in the latter part of this study, have very great advantages over cubic or rectangular shot. The losses of weight of the shot themselves is reduced to a mere trifle, the condition of the charge changes very slowly, and is much cheaper to maintain.

2. The lined steel channel stave has the advantage of any other kind known to the writers in that it can be kept in good order with the minimum expense or attention. The distortion due to peening, which is shown by all staves, is here taken up by the wear-plate, which is inexpensive and easily renewed.

3. The speed of rotation is believed to exert enough influence on the results to justify closer limits than were permitted under the old standards. It is believed to be one very fruitful cause of the difficulties experienced by operators in checking each other.

4. There remain some other factors of the rattler test not covered in the old specifications, which have not as yet been investigated. Their influence may be found to be noticeable by careful study and it may be desirable to cover them by exact specification. Some of these points are (*a*) the method of supporting the rotating barrel; and (*b*), the method of driving the barrel, whether by steam engine, gas engine or electric motor, or by

direct, belt, rope, chain, or friction drive. In the opinion of the writers, no great importance attaches to these factors and some divergence of practice may continue in these respects without destroying the ability of different operators to check each other within the limits which the natural fluctuation of the material itself imposes.

5. The use of a uniform data sheet for recording and reporting rattler tests is very important. It greatly assists in securing uniformity in doing the work.

RECOMMENDATIONS.

In view of the above conclusions we present the following revised specifications for the rattler test upon paving bricks, to take the place of the specifications of the National Brick Manufacturers Association of 1901.

REVISED SPECIFICATIONS FOR THE RATTLER TEST UPON PAVING BRICK.

THE RATTLER

The machine shall be of good mechanical construction, self-contained, and shall conform to the details of material and dimensions, as set forth in the following specifications.

The Barrel.—The barrel of the machine shall be made up of the heads, headliners and staves.

The heads shall be cast with trunions in one piece. The trunion bearings shall not be less than two and one-half ($2\frac{1}{2}$) inches in diameter or less than six (6) inches in length.

The heads shall not be less than three-fourths ($\frac{3}{4}$) inch thick nor more than seven-eighths ($\frac{7}{8}$) inch. In outline they shall be a regular fourteen-sided (14) polygon inscribed in a circle twenty-eight and three-eighths ($28\frac{3}{8}$) inches in diameter. The heads shall be provided with flanges not less than three-fourths ($\frac{3}{4}$) inch thick and extending outward two and one-half ($2\frac{1}{2}$) inches from the inside face of head to afford a means of fastening the staves. The flanges shall be slotted on the outer edge, so as to provide for two (2) three-fourths ($\frac{3}{4}$) inch bolts at each end of each stave, said slots to be thirteen-sixteenths ($\frac{13}{16}$) inch wide and two and three-fourths ($2\frac{3}{4}$) inches center to center. Under each section of the flanges there shall be a brace three-eighths ($\frac{3}{8}$) inch thick and extending down the outside of the head not less than two (2) inches. Each slot shall be provided with recess for bolt head, which shall act to prevent the turning of the same. There shall be for each head a cast iron headliner one (1)

inch in thickness and conforming to the outline of the head, but inscribed in a circle twenty-eight and one-eighth ($28\frac{1}{8}$) inches in diameter. This liner or wear plate shall be fastened to the head by seven (7) five-eighths ($\frac{5}{8}$) inch cap screws, through the head from the outside. These wear plates, whenever they become worn down one-half ($\frac{1}{2}$) inch below their initial surface level, at any point of their surface, must be replaced with new. The metal of which these wear plates are to be composed shall be what is known as hard machinery iron, and must contain not less than one (1) per cent. of combined carbon. The faces of the polygon must be smooth and give uniform bearing for the staves. To secure the desired uniform bearing, the faces of the head may be ground or machined.

The Staves.—The staves shall be made of six (6) inch medium steel structural channels twenty-seven and one-fourth ($27\frac{1}{4}$) inches long, weighing fifteen and five-tenths (15.5) pounds per linear foot.

The channels shall be drilled with holes thirteen-sixteenths ($\frac{13}{16}$) inch in diameter, two (2) in each end, for bolts to fasten same to head, the center line of the holes being one (1) inch from either end and one and three-eighths ($1\frac{3}{8}$) inches either way from the longitudinal center line.

The space between the staves will be determined by the accuracy of the heads, but must not exceed five-sixteenths ($\frac{5}{16}$) inch. The interior or flat side of each channel must be protected by a lining or wear plate three-eighths ($\frac{3}{8}$) inch thick by five and one-half ($5\frac{1}{2}$) inches wide by nineteen and three-fourths ($19\frac{3}{4}$) inches long. The wear plate shall consist of medium steel plate, and shall be riveted to the channel by three (3) one-half ($\frac{1}{2}$) inch rivets, one of which shall be on the center line both ways and the other two on the longitudinal center line and spaced seven (7) inches from the center each way. The rivet holes shall be countersunk on the face of the wear plate and the rivets shall be driven hot and chipped off flush with the surface of the wear plate. These wear plates shall be inspected from time to time, and if found loose shall be at once reriveted, but no wear plate shall be replaced by a new one except as the whole set is changed. No set of wear plates shall be used for more than one hundred (100) tests under any circumstances. The record must show the date when each set of wear plates goes into service and the number of tests made upon each set.

The staves when bolted to the heads shall form a barrel twenty (20) inches long, inside measurement, between wear plates. The wear plates of the staves must be so placed as to drop between the wear plates of the heads. These staves shall be bolted tightly to the heads by four (4) three-fourths ($\frac{3}{4}$) inch bolts, and each bolt shall be provided with lock nuts, and shall be inspected at not less frequent intervals than every fifth (5th) test and all nuts kept tight. A record shall be made after each such inspection, showing in what condition the bolts were found.

The Frame and Driving Mechanism.—The barrel should be mounted on a cast-iron frame of sufficient strength and rigidity to support same without undue vibration. It should rest on a rigid foundation and be fastened to same by bolts at not less than four (4) points.

It should be driven by gearing whose ratio of driver to driven should not be less than one (1) to four (4). The counter shaft upon which the driving pinion is mounted should not be less than one and fifteen-sixteenths ($1\frac{15}{16}$) inches in diameter, with bearings not less than six (6) inches in length and belt driven, and the pulley should not be less than eighteen (18) inches in diameter and six and one-half ($6\frac{1}{2}$) inches in face. A belt of six (6) inch double-strength leather, properly adjusted, so as to avoid unnecessary slipping, should be used.

ABRASIVE CHARGE.

(*a*) The abrasive charge shall consist of two sizes of cast-iron spheres. The larger size shall be three and seventy-five-hundredths (3.75) inches in diameter when new and shall weigh when new approximately seven and five-tenths (7.5) pounds (3.40 kilos) each. Ten shall be used.

These shall be weighed separately after each ten (10) tests, and if the weight of any large shot falls to seven (7) pounds (3.175 kilos) it shall be discarded and a new one substituted; provided, however, that all of the large shot shall not be discarded and substituted by new ones at any single time, and that so far as possible the large shot shall compose a graduated series in various stages of wear.

The smaller size spheres shall be when new one and eight hundred seventy-five-thousandths (1.875) inches in diameter and shall weigh not to exceed ninety-five-hundredths (0.95) pounds (0.430 kilos) each. Of these spheres so many shall be used as will bring the collective weight of the large and small spheres most nearly to three hundred (300) pounds, provided that no small sphere shall be retained in use after it has been worn down so that it will pass a circular hole one and seventy-five-hundredths (1.75) inches in diameter, drilled in a cast-iron plate one-fourth ($\frac{1}{4}$) inch in thickness or weigh less than seventy-five-hundredths (0.75) pounds (0.34 kilos). Further, the small spheres shall be tested by passing them over such an iron plate drilled with such holes, or shall be weighed after every ten (10) tests, and any which pass through or fall below specified weight, shall be replaced by new spheres, and provided, further, that all of the small spheres shall not be rejected and replaced by new ones at any one time, and that so far as possible the small spheres shall compose a graduated series in various stages of wear. At any time that any sphere is found to be broken or defective it shall at once be replaced.

(*b*) The iron composing these spheres shall have a chemical composition within the following limits:

Combined carbon............	Not less than 2.50 per cent.
Graphitic carbon............	Not more than 0.10 per cent.
Silicon.....................	Not more than 1 per cent.
Manganese.................	Not more than 0.50 per cent.
Phosphorus................	Not more than 0.25 per cent.
Sulphur....................	Not more than 0.08 per cent.

For each new batch of spheres used the chemical analysis must be furnished by the maker, or be obtained by the user, before introduction into the charge, and unless the analysis meets the above specifications, the batch of spheres shall be rejected.

BRICK CHARGE.

The number of bricks per charge shall be ten (10) for all bricks of the so-called "block size" whose dimensions fall between from eight (8) to nine (9) inches in length, three (3) and three and three-fourths (3¾) inches in breadth and three and three-fourths (3¾) and four and one-fourth (4¼) inches in thickness. No block should be selected for test that would be rejected by any other requirements of the specifications.

The brick shall be clean and dried for at least three (3) hours in a temperature of one hundred (100) degrees Fahrenheit before testing.

SPEED AND DURATION OF REVOLUTION.

The rattler shall be rotated at a uniform rate of not less than twenty-nine and one-half (29½) nor more than thirty and one-half (30½) revolutions per minute, and eighteen hundred (1,800) revolutions shall constitute the standard test.

A counting machine shall be attached to the rattler for counting the revolutions. A margin of not to exceed ten (10) revolutions will be allowed for stopping. Only one (1) start and stop per test is regular and acceptable.

CALCULATION OF THE RESULTS.

The loss shall be calculated in percentage of the original weight of the dried brick composing the charge. In weighing the rattled brick, any piece weighing less than one (1) pound shall be rejected.

RECORDS.

(*a*) The operator shall keep an official book, in which the alternate pages are perforated for removal. The record shall be kept in duplicate, by use of a carbon paper between the first and second sheets, and when all entries are made and calculations are completed the original record shall be removed and the carbon duplicate preserved in the book. All calculations must be made in the space left for that purpose in the record blank, and the actual figures must appear. The record must bear its serial number and be filled out completely for each test, and all data as to dates of inspection and weighing of shot and replacement of worn-out parts must be carefully entered, so that the records remaining in the book constitute a continuous one. In event of further copies of a record being needed, they may be furnished on separate sheets, but in no case shall the original carbon copy be removed from the record book.

(*b*) The blank form upon which the record of all official brick tests is to be kept and reported is:

REPORT OF
STANDARD RATTLER TEST OF PAVING BRICK

IDENTIFICATION DATA Serial No.................

Name of the firm furnishing sample..
Name of the firm manufacturing sample..
Street or job which sample represents..
Brands or marks on the brick..
Quantity furnished ....Drying treatment ....
Date received..............................Date tested..............................
Length..............................Breadth..............................Thickness ....

STANDARDIZATION DATA

Number of charges tested since last inspection

Weight of Charge (After Standardization)	Condition of Locknuts on Staves	Condition of Scales
10 Large spheres		
Small spheres		
Total		

Number of charges tested since stave linings were renewed
Repairs (Note any repairs affecting the condition of the barrel)

RUNNING DATA

Time Readings				Revolution Counter Readings	Running Notes, Stops, etc.
	Hours	Minutes	Seconds		
Beginning of test.					
Final Reading....					

WEIGHTS AND CALCULATIONS

		Percentage Loss (Note.—The Calculation Must Appear)
Initial Weight of 10 Bricks...		
Final Weight of Same........		
Loss of Weight..............		

Number of broken bricks and remarks on same..

I certify that the foregoing test was made under the specifications of

....

....and is a true record.

(Signature of Tester)

Date......................... ....
Location of Laboratory

For the use and convenience of others, a drawing of a machine which meets the above specifications is furnished herewith. It is not a part of the specifications. It is important, however, in the

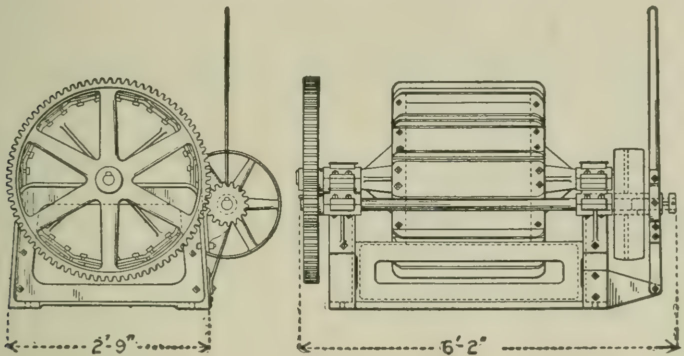

FIG. 9.

opinion of the writers, that uniformity in apparatus and equipment shall prevail to the largest possible extent, as an aid in securing uniformity of results, and close adherence to the type of machine here presented is therefore greatly to be desired.

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SUPERHEATED STEAM

By Embury A. Hitchcock

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Superheated Steam

By Embury A. Hitchcock

It is the purpose of the writer to deal with only that phase of the subject of superheated steam in so far as it relates to the results obtained during some experimentation[1] in the Mechanical Engineering Laboratories of The Ohio State University.

During the fall of 1910 there was installed in the fuel and gas testing laboratory of the Department of Mechanical Engineering a Foster independently fired superheater, which is shown in Fig. 1 just at the left of the Robinson Babcock & Wilcox experiment boiler, and also shown in section in Fig. 2. This superheater, which has a rated capacity of 3500 lb. of steam per hour raised to a temperature of 602 deg. fahr. at a pressure of 125 lb. and a safe working pressure of 180 lb., is made up of 21 elements connected to steel manifolds and return headers. An element is shown in part section in Fig. 3 connected to a section of a manifold. The joints between the elements and manifolds or headers are metal to metal, made by expanding the ends of the elements into the reamed holes, making same sufficiently tight to stand a cold water test of 225 lb. These elements are made up of seamless, cold drawn steel tubing, the outside of which is completely covered with snugly fitting cast iron grill flanges. This cast iron covering protects the steel tubing against local overheating and action of the gases. It furnishes additional surface for heat absorption and provides a mass of metal for storage of heat, which at the same time serves as a heat equalizer between the variable temperature of the products of combustion and the steam being superheated. Each element has an internal diameter of 1.8 in. and is fitted with a

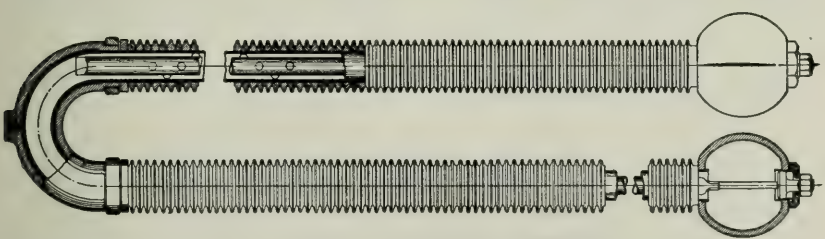

FIG. 3. SECTION OF SUPERHEATER ELEMENT.

cylindrical core of wrought iron tubing 1.32 in. diameter, closed at each end and provided with knobs regularly spaced throughout its length so that this core will be held centrally in the element

[1] A thesis for the degree of Mechanical Engineer on the subject of superheated steam by Messrs. Cochrane, Foster and Pape.

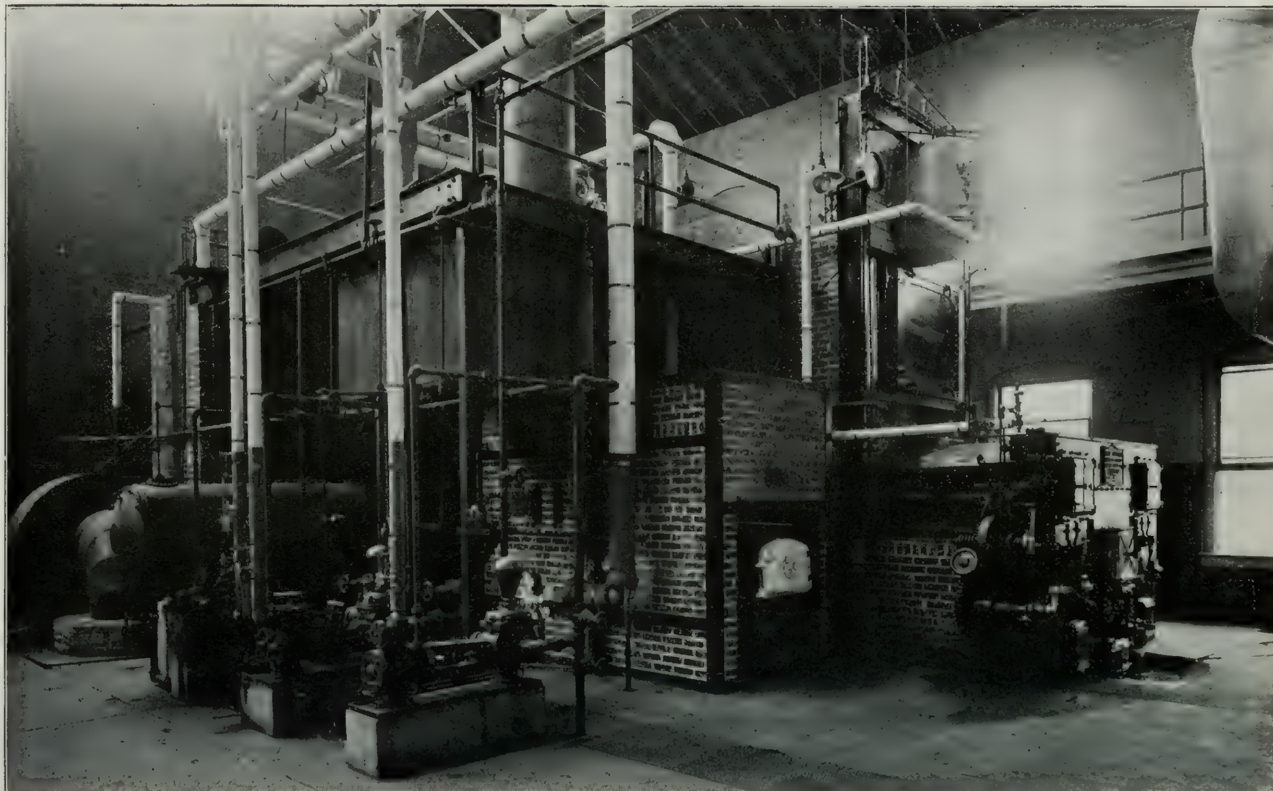

FIG. 1. FOSTER SUPERHEATER AND ROBINSON EXPERIMENTAL BOILER

and thus form a thin annular passageway for the steam, compelling it to travel in close proximity to the heating surface. The above internal and external diameters give a clear passageway for

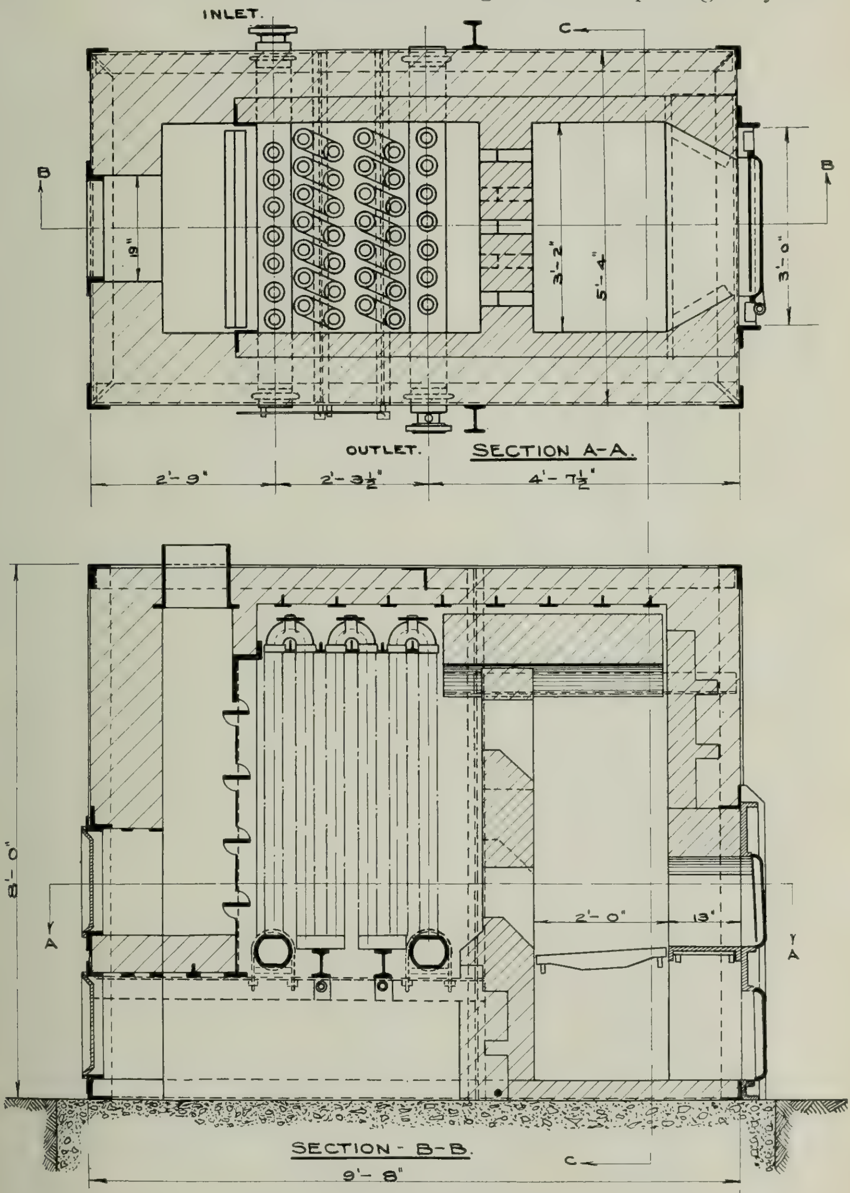

FIG. 2. SECTIONS OF SUPERHEATER

each element of 1.176 sq.in., and as there are 7 sections in this superheater, the total area for steam passage is 8.23 sq.in. as compared with 6.835 sq.in., the area of 3 in. extra heavy pipe leading to and from the superheater. The effective heating surface

for each element, not counting return bends, is 4.0444 sq.ft., thus making a total heating surface of 84.92 sq.ft. with headers and manifolds not considered. With the grate value equal to 6.33 sq. ft., the ratio of grate area to internal heating surface is as 1 to 13.4.

Since the rating of this superheater is the raising of 3500 lb. of steam per hour from a pressure of 125 lb. by gage, to a temperature of 602 deg. fahr., considering the steam supplied as dry, the average heat transmission per square foot of internal heating surface is 5358 B.t.u. per hr., which is 58 per cent. greater than for the average boiler heating surface, based on the usual average evaporation of 3.5 lb. from and at 212 deg. fahr. per sq.ft. of heating surface.

The supply line to this superheater is so connected to the piping system that at any time steam may be taken from the main laboratory steam header. This steam is usually supplied from the University boiler house at a pressure of 115 lb. or, when operating the Babcock & Wilcox boiler shown in Fig. 1, under pressures up to 180 lb. All or part of the steam generated by the B. & W. boiler can be passed through the superheater. The 3 in. superheat discharge line rises a distance of 19 ft. 1 in., runs horizontally 19 ft. 11 in. through the wall into the steam section of the main laboratory where it connects to the 3 in. main superheated steam header which rests on the same wall brackets as the saturated steam header, between this header and the wall, as shown in Fig. 4. This superheat header has a straight run of 69 ft. with branches so that superheated steam can be supplied to most of the steam driven units in the laboratory steam section. One 3 in. branch rises from the top of this header at its end, runs horizontally 23 ft. 6 in. and drops to a 60 horse-power McEwen tandem compound engine, connected to a Wheeler surface condenser.

This engine was used for the purpose of determining what may be expected in the way of reduction in steam consumption produced by the use of superheated steam for an engine of this type or class. In order to vary the conditions as to the quantity of steam flowing through the superheat header and at the same time be independent of other apparatus, a direct pipe connection controlled by two valves was made from the superheat line to the surface condenser.

The experimental work as conducted, the general results of which are herewith given, may be outlined as follows:

First. Running superheater under different conditions as to pressure and quantity of steam, and noting drop in pressure and temperature from superheater to far end of header, and also noting drop in temperature of steam along header a distance of 66 ft., with all lines without covering.

Second. Similar trials on lines having double covering.

Third. Conducting a complete heat balance test upon superheater in order to estimate the fuel costs for superheating.

Fourth. Determining reduction in steam consumption of McEwen tandem compound engine when running with superheated steam.

FIG. 4. SATURATED AND SUPERHEATED STEAM HEADERS

With these facts available we are then able to compute the net gain in fuel due to the use of this particular superheater in conjunction with this particular engine or with any steam driven unit having once determined the reduction in water rate due to superheat.

STEAM LINE TRIALS

In preparing for the pipe-line trials all gages and thermometers were calibrated and the readings here given are so corrected. In conducting such trials the quantity of steam flowing through the superheater and line was maintained constant for sufficient length of time before the trial began to secure continuity conditions. In order to obtain the average external temperature and thus reduce all results to loss in B.t.u. per square foot per degree difference in temperature, three thermometers were suspended along and about six feet directly underneath the header. The total distance from superheater to the end of the header or gage to gage, is 121 ft. and the line contains 2 tees and 3 elbows. The square feet of radiating surface is based upon the outside dimensions of the pipe line. This surface for the header between the points at which the temperatures were taken is 61.3 sq.ft.

Immediately following the trials on the uncovered lines, these were then covered double with H. W. Johns-Manville 1 in. fire felt and 1 in. 85 per cent. magnesia. The results obtained on the uncovered and covered lines and header are given in the following table:

TABLE 1.

	PRESSURE Lbs.		TEMPERATURE Fahr.											
	Leaving superheater	End of header	Leaving superheater	Header entrance	End of header	Room	Drop in pressure from superheater to end of header.	Drop in temperature from superheater to end of header.	Drop in temperature along header.	Total lbs. of steam through header per hour.	Velocity of steam through header, ft. per minute.	B.t.u. loss per hour from header.	B.t.u. loss per hour per sq. ft.	B t.u. loss per hour per sq. ft. per degree difference in temperature.
UNCOVERED	80.0	76.3	388.0	361.4	335.0	86.9	3.7	53.0	26.4	3,559	6,550	50,800	795	3.08
	79.5	77.0	422.0	375.5	336.0	83.3	2.5	86.0	39.5	2,431	4,505	50,900	796	2.96
	78.5	77.0	513.0	399.1	334.5	84.1	1.5	78.5	64.6	1,268	2,387	43,400	687	2.43
	97.6	94.2	402.5	371.7	346.0	86.2	3.4	56.5	25.7	3,656	5,635	52,600	833	3.06
	95.6	95.0	445.5	389.5	345.5	77.4	0.6	100.0	44.0	2,243	3,500	54,250	858	2.96
	96.5	95.4	550.0	404.1	343.0	81.3	1.1	107.0	61.1	1,130	1,780	38,000	602	2.06
	124.9	121.8	424.0	391.4	362.1	83.2	3.1	61.9	29.3	3,672	4,630	62,400	988	3.36
	124.0	123.0	504.0	423.8	369.5	83.4	1.0	134.5	54.3	2.000	2,560	60,900	964	3.07
COVERED	79.1	77.6	343.5	342.8	334.6	88.9	1.5	8.9	8.2	2,496	4,500	11,210	178	.713
	77.5	77.3	354.3	346.7	335.0	90.5	0.2	19.3	11.7	1,237	2,230	7,920	126	.503
	97.3	94.4	350.2	348.2	344.0	87.7	2.9	6.2	4.2	3,408	5,140	7,990	127	.493
	96.3	94.9	350.1	348.0	342.5	89.4	1.4	7.6	5.5	2,540	3,826	7,800	123	.483

The results obtained for the uncovered pipe tests check the general value usually taken for heat loss per British thermal unit per hour per degree difference in temperature for uncovered pipe, that is 3 B.t.u., but at the same time there is shown a drop in this

loss with a drop in velocity of the steam through the line. The results obtained with the line covered run somewhat above the values usually given for cases of covered line, and, with the exception of the first trial of this set, the results indicate a practically constant loss under variable conditions. It will be observed that the temperatures carried in the line were such as to give a small amount of superheat at the end of the header.

SUPERHEATER TRIAL

In preparing for a test of the superheater, a Barrus calorimeter and pressure gage were connected to the supply line close to the superheater, in addition to a pressure gage and a Hohmann & Maurer standard thermometer at the outlet. For obtaining the drafts and the temperature of the escaping gases Ellison inclined draft gages and Hohmann & Maurer mercurial pyrometer were used. An Orsat apparatus with continuous gas sampler and collector was used for obtaining composition of the escaping gases. In order to have the superheater in a well heated condition, it was fired up at 1 a.m. of the day of the trial and run steadily until the test began at 7:45 a.m.

The following are the general results obtained:

GENERAL DIMENSIONS OF SUPERHEATER

Number of elements	21
Diameter tubes, internal, inches	1.8
Diameter tubes, external, inches	2.0
Length of element	4 ft. 3.5 in.
Area heating surface inside, sq.ft.	84.92
Kind of furnace	Hand fired, shaking grate
Dimension of grates, 3 ft. 2 in. by 2 ft. 6 in., sq.ft.	6.33
Ratio of grate area to inside heating surface	1 to 13.4
Area opening into flue, sq.ft.	2
Floor space, 9 ft. 8 in. by 5 ft. 4 in., sq.ft.	51.2

CONDITIONS

Date of trial	June 6, 1911
State of weather	Clear
Duration of trial, hours	10
Kind of fuel	Pocahontas Run of Mine

AVERAGE PRESSURES

Steam pressure by gage, entering superheater, lb.	107.7
Atmospheric pressure by barometer, inches	29.25
Absolute steam pressure, lb.	122.1
Steam pressure by gage, leaving superheater, lb.	100.2
Steam pressure by gage, end of header, lb.	95.
Force of draft over fire, inches	0.036
Force of draft leaving superheater, inches	0.091

AVERAGE TEMPERATURES

Fire room, deg. fahr.	90.2
Products of combustion leaving superheater, deg. fahr.	580.3
Steam leaving superheater, deg. fahr.	564.8

FUEL

Kind of firing	Spreading
Thickness of fire, inches	4
Weight of coal fired during trial, lb.	828
Weight of refuse, lb.	43
Per cent. refuse to coal, per cent.	5.18
Proximate analysis in per cent.	
Moisture	0.96
Volatile matter	19.06
Fixed carbon	75.82
Ash	4.16
Ultimate analysis in per cent.	
Carbon	87.35
Hydrogen	4.26
Oxygen	2.65
Nitrogen	0.86
Sulphur	0.72
Ash	4.16
Analysis refuse in per cent.	
Combustible	22.
Ash	78.
Calorific value of fuel by Mahler calorimeter, B.t.u.	14986

QUALITY OF STEAM

Moisture in steam entering superheater, per cent.	1.00

STEAM

Weight of wet steam entering superheater, lb.	45892
Weight of dry steam entering superheater, lb.	45433
Weight of water entering superheater, lb.	459

STEAM PER HOUR

Weight of water evaporated and superheated, lb.	45.9
Weight of dry steam superheated, lb.	4543.3

ECONOMIC RESULTS

Water evaporated and superheated per lb. coal, lb.	0.544
Steam superheated per lb. coal, lb.	54.866
B.t.u. taken up by water per lb. coal	549.3
B.t.u. taken up by steam per lb. coal	6337.0
Total B.t.u. per lb. of coal	6886.3
Efficiency of superheater, per cent.	45.95

FLUE GAS ANALYSIS

Carbon dioxide, CO_2, by volume	7.11
Oxygen, O	12.70
Carbon monoxide, CO	0.00
Nitrogen, N	80.19

HEAT BALANCE PER LB. COAL

	B.t.u.	Per cent.
Loss due to latent heat	392	2.62
Loss due to products of combustion	1470	9.82
Loss due to air excess	2010	13.42
Loss due to unburned coal	164	1.09
Loss due to radiation, etc.	4064	27.10
Heat used in superheating	6886	45.95
Total heat supplied	14986	100.

At first glance, the efficiency obtained, 45.95 per cent., would seem low, but when one considers the size of the superheater and the area of the fire door in relation to the grate area, the results obtained are to be expected. The heat taken up per hour per square foot of internal heating surface was 6714 B.t.u., or 25 per cent. in excess of the superheater rating. The maximum velocity of the steam through the elements was 7000 ft. per min. with a drop through the superheater of 7.5 lb. and a drop from superheater to the end of the header of 5.2 lb. with an average velocity in the line of 8500 ft. per min.

ENGINE TRIALS

The McEwen engine as shown in Fig. 5 is of the horizontal tandem compound type with inertia governor arranged to cut off

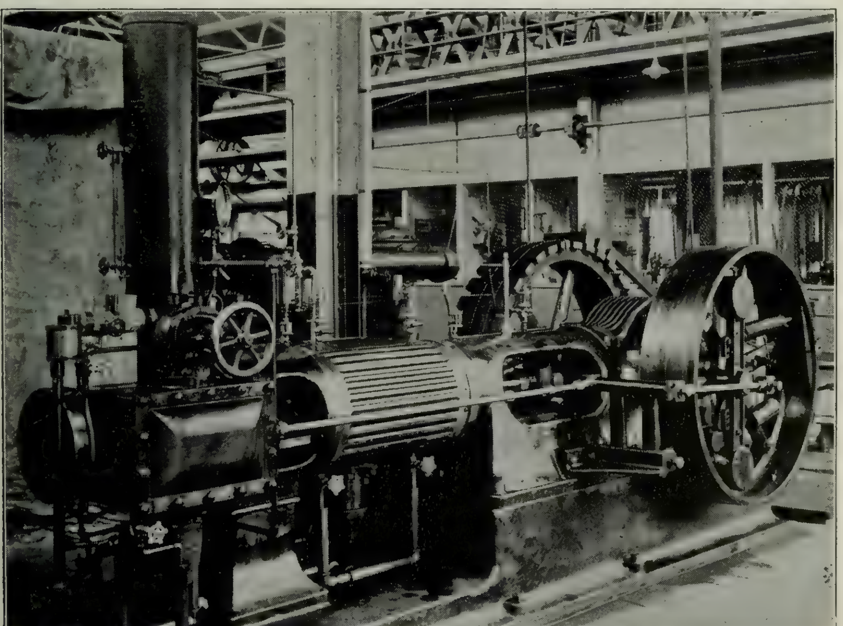

FIG. 5. McEWEN TANDEM COMPOUND ENGINE

on the high-pressure cylinder only. This unit, although having seen many years of service in the University power house, was in very good condition for these trials in that after its removal from the power house to the Experimental Laboratory, the cylinders were rebored, valve seats refaced and new pistons and valves with rods provided. It was also refitted in other respects.

In preparing for these trials the unit was fitted with pressure and vacuum gages, Barrus calorimeter, continuous counter, prony brake and Crosby and Tabor outside spring indicators. During the superheater trials the temperature of the steam was taken in the high-pressure steam chest.

The following are the general results obtained:

ENGINE DIMENSIONS

Diam. high-pressure cylinder, inches	8.2
Diam. high-pressure rod, inches	1.75
Clearance high-pressure cyl., head end, per cent	12.71
Clearance high-pressure cyl., crank end, per cent	13.64
Diam. low-pressure cylinder, inches	13.24
Diam. low-pressure rod, inches	2.25
Clearance low-pressure cyl., head end, per cent	11.86
Clearance low-pressure cyl., crank end, per cent	11.23
Stroke, inches	12.

RESULTS

Number of run	1	2	4	5
R.p.m. continuous counter	284	289	285	286
Pressure at throttle by gage, lb.	110	109.2	100.4	100.5
Pressure in receiver, lb.	1.3	6.7	3.8	6.1
Vacuum in exhaust line at engine, inches	25.3	25.3	25	24.9
Moisture in steam at throttle, per cent.	1.26	1.92		
Temperature of steam in steam chest, deg. fahr.			419.4	427.2
Degrees superheat in steam chest, deg. fahr.			81.3	89
Weight of dry steam per hr. from condenser, lb.	843	1113	858	1036.5
I.h.p. high-pressure cylinder	13.89	23.78	23.44	31.35
I.h.p. low-pressure cylinder	20.84	28.70	23.07	28.66
I.h.p. total	34.73	52.48	46.51	60.01
Dry steam per i.h.p. hr., lb.	24.28	21.23	18.44	17.27
Thermal efficiency, per cent	9.54	10.91	12.15	12.92

The results obtained per lb. of dry steam per i.h.p. per hr. on the two trials with saturated steam, when referred to a water-rate curve for this same engine obtained a short time previous to these trials while running under practically the same conditions through a range of six loads varying from 36.5 to 77.5 i.h.p., exceed those results by about 0.1 lb. of steam per i.h.p. hour, or a difference of 0.5 per cent. Therefore, referring to this water-rate curve for the loads carried on the superheat trials, the rates for

saturated and superheated steam for the 46.51 and 60.01 i.h.p. loads are 22.25 and 20.1 lb. as against 18.44 and 17.27 lb., or an excess of steam for the ¾ load of saturated over superheated of 20.6 per cent., and for the full load 16.9 per cent.

Although the use of superheated steam in this unit, as well as others, shows a marked degree of reduction in the weight of the steam used, this does not indicate the fuel or net saving as all losses and additional fuel costs to produce the superheat are not taken into consideration.

Taking the case of an assumed plant of such a capacity as to require a superheater of the size of the one under consideration, and considering this plant with and without the superheater, the difference in fuel consumption could be computed as herewith shown.

This assumed plant is to have a normal capacity equal to that of the superheater when giving, say, 100 deg. fahr. superheat at 120 lb. gage pressure. From the above superheater test, considering the same efficiency as obtained, this capacity would be 8890 lb. of steam per hour and on a basis of 17.27 lb. of steam per i.h.p. hour for the engine water rate, would give an engine or engines of 510 i.h.p. Consider the line from the superheater to the engine to be extra heavy 3.5 in. pipe and 100 ft. in length with double covering. The velocity of the steam through this line would be 8300 ft. a minute, with a loss in heat due to radiation, of 2 B.t.u. per lb. of steam, or a drop in superheat of 3.6 deg. fahr. The drop in the pressure through the superheater would probably be 15 lb., with a drop through line of 5 lb., or a total drop of 20 lb., giving a pressure at the engine of 100 lb. Taking the efficiency of the superheater practically the same as that obtained on the test, or 45 per cent., and figuring on a good grade of Hocking coal having 12 000 B.t.u. per lb., the coal required per hour for superheat would be 105.5 lb. Considering the boiler generating the steam and using the same coal, and having an efficiency of 65 per cent., the coal required per hour by the boiler with a gage pressure of 120 lb. and a feed water temperature of 200 deg. fahr. would be 1156 lb., or a total for boiler and superheater of 1261.5 lb.

Eliminating the superheater and considering the engine using saturated steam only, the total steam required by the engine would then be 10 251 lb. per hr. Taking the usual saturated steam velocity of 6000 ft. per min., the estimated steam line diameter would be 4.5 in. and in all probabilities in practice, a 5 in. line would be installed. This size line would give a radiation loss of 18 750 B.t.u. per hr., which would be equivalent to the condensation in the line of 21 lb. of steam per hour, thus making the total dry steam required from the boiler 10 272 lb. per hr. Consider as before the boiler efficiency as 65 per cent. at a pressure of 105 lb. and a feed water temperature of 200 deg. fahr., the coal required per hour would be 1343 lb., an increase of 81.5 lb. per hour, or 6.45 per cent., which would stand for a saving for a working year of 3000 hrs. of 122.2 tons.

In considering the financial aspect of the problem the elements entering in are the number of hours the plant is in operation, the cost of fuel, additional operating costs (if any), depreciation, etc. These elements would vary with each individual plant depending upon its location, character of design and construction, and its operation, so therefore the advisability of using superheated steam in any plant is a problem for owner, designing or operating engineer.

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TESTS OF A SAND-BLASTING MACHINE

BY

WILLIAM T. MAGRUDER

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TESTS OF A SAND-BLASTING MACHINE

By Wm. T. Magruder

ABSTRACT OF PAPER

The paper gives the records and results of quantitative tests of a sand-blasting machine under the actual conditions of commercial practice. The rough surfaces of pieces of cast iron, which had been cast in one mold, were blasted by air, from which the moisture had been separated, with dried and screened new Cape May grit by a Pangborn sand-blasting machine, and with the sand valve wide open. The quantity of air used was measured by a pitotmeter; the quantities of iron removed, of sand used, and of sand consumed, were measured for each test. The air pressure was varied from 20 lb. to 70 lb. The angle between the surface of the test bar and the nozzle was varied from 30 to 90 deg. The distance from the nozzle to the test bar was varied from 4 to 10 in.

The results show that (*a*) for distance of 8 in. and angle of 45 deg., the equivalent amount of free air delivered per minute, the iron removed, the sand discharged, the sand used up, per 100 cu. ft. of free air flowing per minute, vary directly with the pressure; the amount of usable sand remaining and the amount of sand discharged per pound of iron removed vary inversely with the pressure; (*b*) for 60 lb. pressure and 8 in. distance, the largest amount of iron was removed and the least amount of sand was required to do it, when the angle between the nozzle and the work was from 45 to 60 deg.; (*c*) for 60 lb. pressure and 45 deg. between the nozzle and the work, the largest amount of iron was removed and the least amount of sand was required to do it, when the distance was 6 in.; (*d*) the sand used up varies with the directness of the blast; and (*e*) inversely with the distance from the test bar.

TESTS OF A SAND-BLASTING MACHINE

By Wm. T. Magruder, Columbus, Ohio

Member of the Society

This paper gives the records, results and conclusions of a series of quantitative tests of a sand-blasting machine, under the actual conditions of commercial practice, which were made by David H. Ebinger and Robert A. Frevert, of Columbus, under the direction of the author as their thesis for the degree of mechanical engineer from The Ohio State University in 1910. The variables in the problem were: (*a*) the material to be sand-blasted; (*b*) the character of its surface; (*c*) the air-pressure best to use with different materials and conditions; (*d*) the size of nozzle for different classes of work; (*e*) the angle to the surface of the work at which the nozzle should be held; (*f*) the distance from the work at which the nozzle should be held; (*g*) size, sharpness, kind, character, uniformity of size, and cleanliness of the sand, and the number of times it has been previously used for sand-blasting; (*h*) the relative dryness of the sand and of the compressed air of the blast; (*i*) the proportion of sand to air; (*j*) differences in commercial machines.

2 As it was evident that a complete solution of the problem was impossible in the time available, certain of the variables were made constant as follows:

- *a* The material was pieces of cast iron which had been broken as test bars for transverse tests. They were 2 in. by 4 in. in cross-section and from 15 to 25 in. long. They had been cast diagonally on edge in one mold from one ladle of machinery iron.
- *b* Their rough surfaces were as uniform as were the bars themselves.

The American Society of Mechanical Engineers, 29 West 39th Street, New York. All papers are subject to revision.

c A new nozzle, $\frac{5}{16}$ in. in diameter, was used for each test. To remove any unevenness of the interior surface of the nozzles, and to bring them all exactly to the same condition, sand was blown through each for 2 minutes previous to starting the tests. No tests have yet been made with other sizes of nozzles.

d The sand used was a No. 3-J Cape May grit, new, hard, sharp, clean, free from clay, and was such as is commonly used by the trade. It was obtained from a large storage bin in the works. It was thoroughly dried in a Pang-

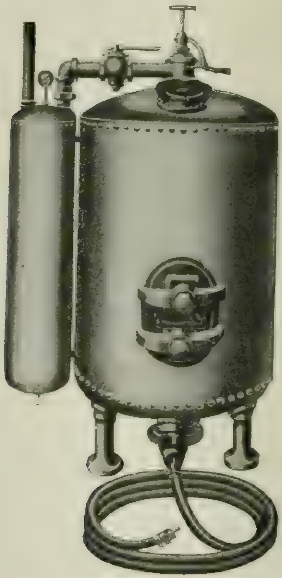

Fig. 1 Sand-Blasting Machine

born No. 1, Type M, sand dryer, shortly before being used. Great care was taken to avoid overheating it and so destroying its strength and cohesion. The sand was then passed through a No. 8 mesh screen. After use in the machine, it was weighed, sifted, reweighed, and discarded. New sand was used for each test.

e The sand was dried as above described. The compressed air was passed through a separator to relieve it of moisture from the atmosphere and oil from the compressor.

f No attempt was made to regulate and adjust the propor-

tion of air to sand. All tests were run with the regulating valve wide open.

g No comparisons were made of the operations or results from different machines on the market.

3 Upon the three remaining variables, the air pressure, the angle between the surface of the work and the nozzle, and its distance from the work, the quantitative experiments were made.

EQUIPMENT

4 The regular equipment of the D. A. Ebinger Sanitary Manufacturing Company at Columbus, Ohio, was used for these tests. It

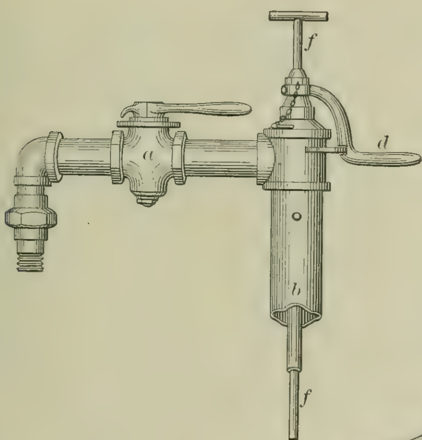

Fig. 2 Regulating and Controlling Valves

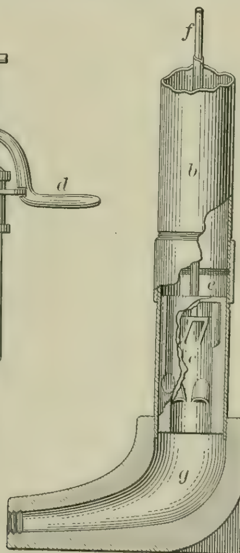

Fig. 3 Mixing Chamber for Air and Sand

had been recently installed for use in sand-blasting cast-iron ware before enamelling. It consisted of one No. 8, Type C, sand-blasting machine, made by the Thomas W. Pangborn Company, Jersey City, N. J., having a sand capacity of 4000 lb. per charge. It was provided with a moisture separator, pneumatic sand separator, dust catcher, and exhaust fan. The air was compressed by a Fairbanks, Morse & Company air compressor, having a capacity of 138 cu. ft. of free air per minute, and driven by an opposed gas engine of 25 h.p. capacity.

5 Fig. 1 shows the machine and Fig. 2 the regulating and controlling valves. Fig. 3 shows the mixing chamber for the air and sand. Fig. 4 shows a plan of the rooms and apparatus. Fig. 5 shows the sand-blasting box and sand-catcher. Fig. 6 shows a photograph of the machine, blasting room and apparatus. Table 1 gives the record of the tests and the results. Figs. 7 to 9 graphically show the results obtained.

OPERATION OF THE MACHINE

6 The compressed air, coming from the compressor, enters the moisture and oil separator at the left of the machine, passes through

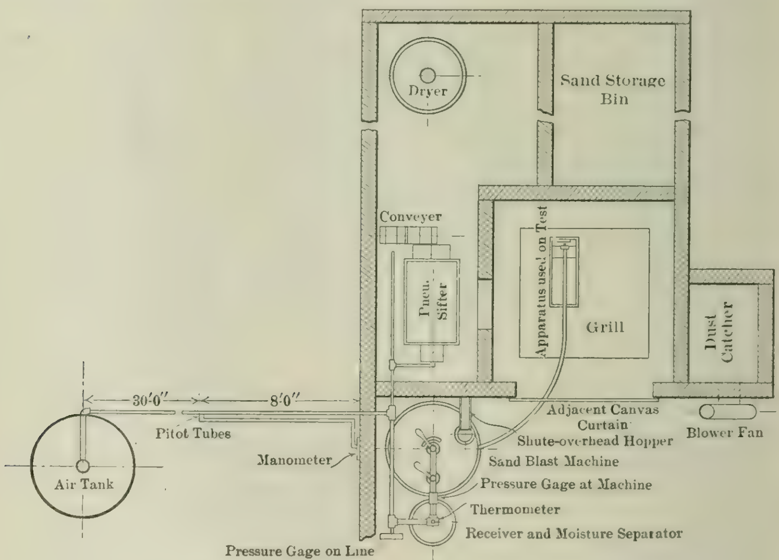

Fig. 4 Location and Arrangement of Apparatus

the air regulator *a*, which has an indicator-handle working over a graduated disc, enters and passes down through the cylinder *b*, inside the machine, then through the air ports in the piston *c*, and engages the entering sand. The ports in the top of the cylinder, one of which is shown, deliver the air to the sand chamber, so as to maintain equal pressure above the sand and to assist in insuring uniform flow. The sand-controller handle, *d*, moves on a quadrant, having limit stops for its off and on full positions. This handle permits the piston *c*

to be rotated in its casing *e*, thereby opening, regulating and closing the sand ports by a single control. The stirrer and handle *f* connect with its fork which operates inside of the piston and mixing chamber for dislodging caked sand that may form under certain conditions. Ports, elliptical in shape, are located in opposite sides of both the piston *c* and the casing *e*, and are inclined downwards, so starting the flow of the sand by gravity. The rotation of the piston by the controller handle regulates the opening of the ports and the flow of sand. The sand on leaving the ports is met by the air coming through the ports in the piston. They cross each other from opposite sides into the mixing chamber *g*. By this cross flow, a swirl-

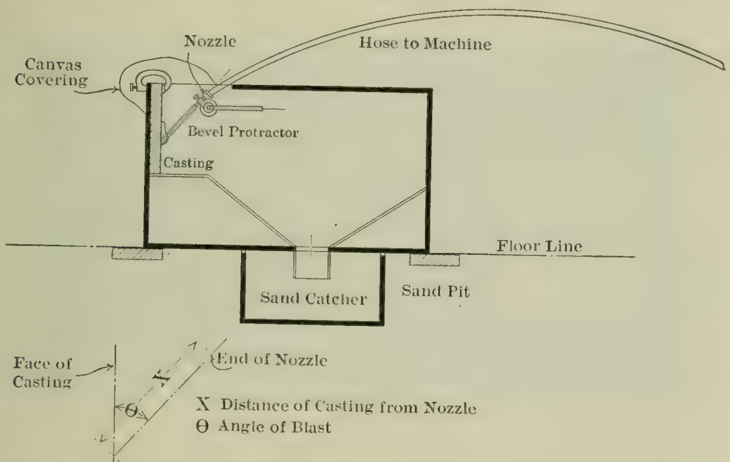

Fig. 5 Sand-Blasting Box and Sand Catcher

ing motion is produced and a thorough mixture of the sand and air is obtained in the rear part of the mixing chamber. The mixture is carried forward by the air pressure from the rear part, $2\frac{1}{2}$ in. in diameter, to the hose connection where it is $\frac{3}{4}$ in. in diameter, thence through the hose to the nozzle, whence it is projected upon the casting to be sand-blasted.

MEASUREMENT OF THE AIR

7 The air used was measured by a pitotmeter placed horizontally in a run of straight $1\frac{1}{2}$-in. standard welded pipe in the main air line, and located at a distance from any fitting. The opening,

$\frac{1}{8}$ in. in diameter, of the dynamic tube faced the current of air from the receiver tank. The end of the static tube was trimmed off flush with the interior of the pipe. The tubes were connected by $\frac{1}{8}$-in. pipes to the ends of a water manometer. The difference in the levels of the liquid in the two legs of the manometer indicated the difference between the dynamic and static pressures, and is a measure of the velocity head in inches of water. From the formula, $v^2 = 2gh$, the velocity of the air in the pipe was calculated. Deducting the area of the dynamic tip from the area of the opening in the pipe, gave the net area of the air pipe. The coefficient of discharge was taken as 0.91. To remove the moisture that collected in the tubes, valves were placed in each of the tubes above the manometer, and pet cocks

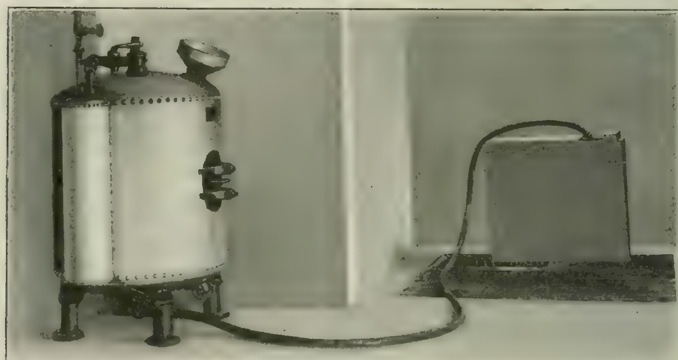

Fig. 6 View of Machine and Apparatus in Blasting Room

placed in the tubes directly above the valves. This arrangement permitted the blowing out of each tube before taking a reading of the pitotmeter. The temperature of the air in the line was taken just before it entered the stop valve at the machine. Calibrated pressure gages in the line and at the machine gave the desired pressures.

MEASUREMENT OF THE SAND

8 To collect the sand used during each test and also to control the blast, a closed box with a hopper bottom and a shelf at one end to support the test bar was prepared, as is shown in Fig. 5. The sand discharged during a test was collected in the hopper, removed, and weighed as total sand used. It was then sifted, and again weighed, thus giving by difference the amount of sand rendered useless by the

test, and the amount of sand that might be used again in commercial practice. It was not again used in these tests.

MEASUREMENT OF THE IRON REMOVED

9 The test bar was held in a vertical position in the sand-blasting box. Before and after blasting, it was carefully weighed on a plat-

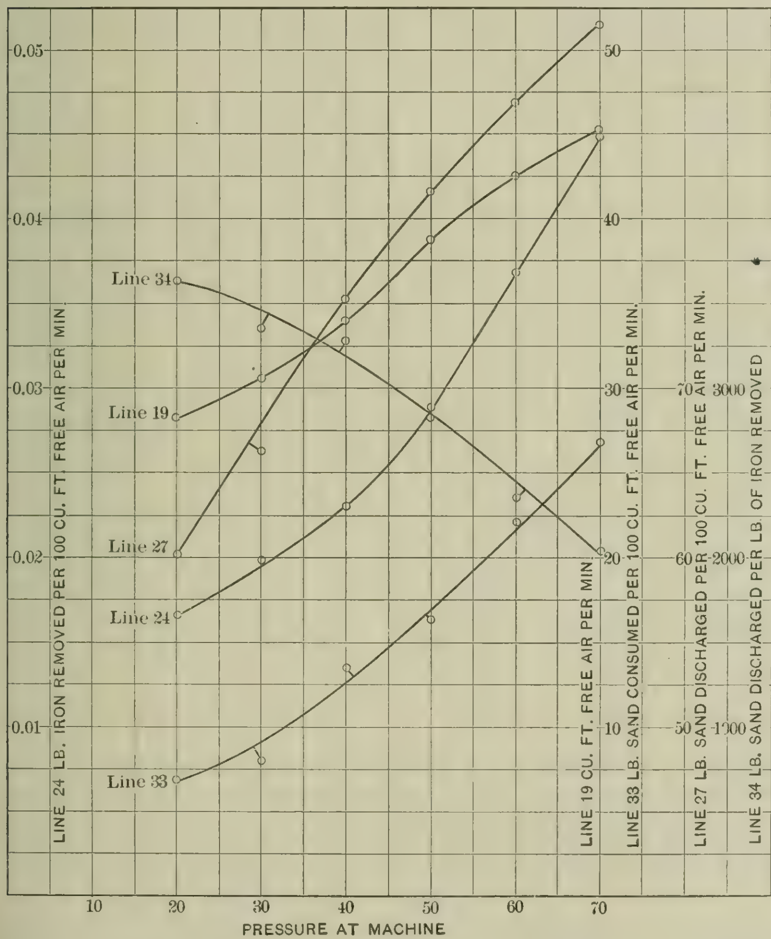

FIG. 7 RESULTS OF TESTS IN RELATION TO AIR PRESSURE AT MACHINE

form scale of 250 lb. capacity by quarter ounces. The scale was carefully balanced before each weighing.

METHOD OF MAKING THE TESTS

10 In each test the new nozzle was first brought to a uniform condition by discharging a blast of sand and air through it for 2 minutes under a constant blast pressure. The test bar was weighed and placed in position in the closed hopper box. The nozzle was then set by scale for its distance from the test bar and by bevel protractor for its angle with the surface of the test bar. The air regulator *a* was kept wide open during the tests. The desired air pressure in the

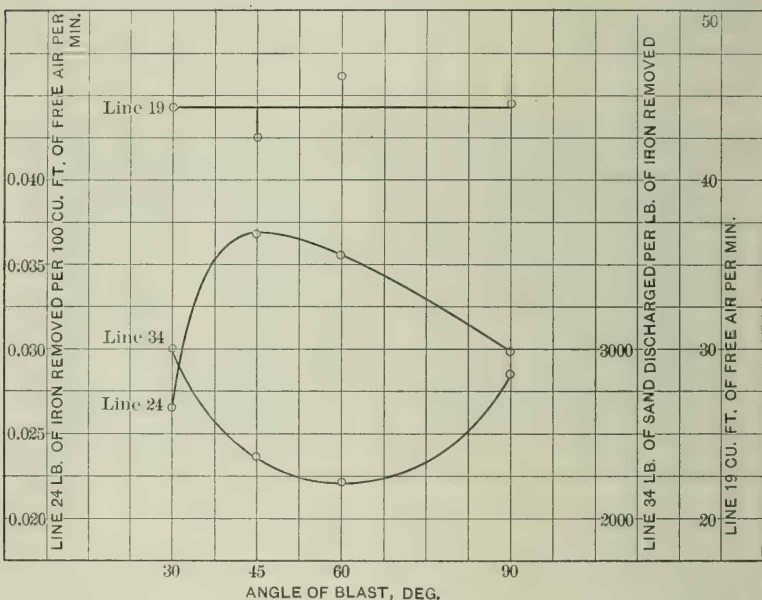

Fig. 8 Results of Tests in Relation to Angle of Blast

machine was secured and maintained constant by adjusting the stop valve in the supply pipe to the moisture separator. After starting the air blast and carefully adjusting the valve to maintain a constant pressure at the machine, the sand-controller handle *d* was moved to its open position at the instant of starting, thus allowing sand to flow into the mixing chamber and be forced by the blast of air out through the nozzle and against the test piece. Readings of the temperature and pressures of the air on the main line and at the machine were taken at regular intervals of about 2 minutes. In closing down the machine at the end of a test, the sand valve was first closed and

then the air valve; the test bar was weighed, and the difference of the two weights gave the amount of iron removed; the sand discharged was weighed, sifted and again weighed.

VARIABLES OF THE TESTS

11 Starting at 20 lb. corrected pressure at the machine on the first test, and increasing by 10 lb. up to and including 70 lb. pres-

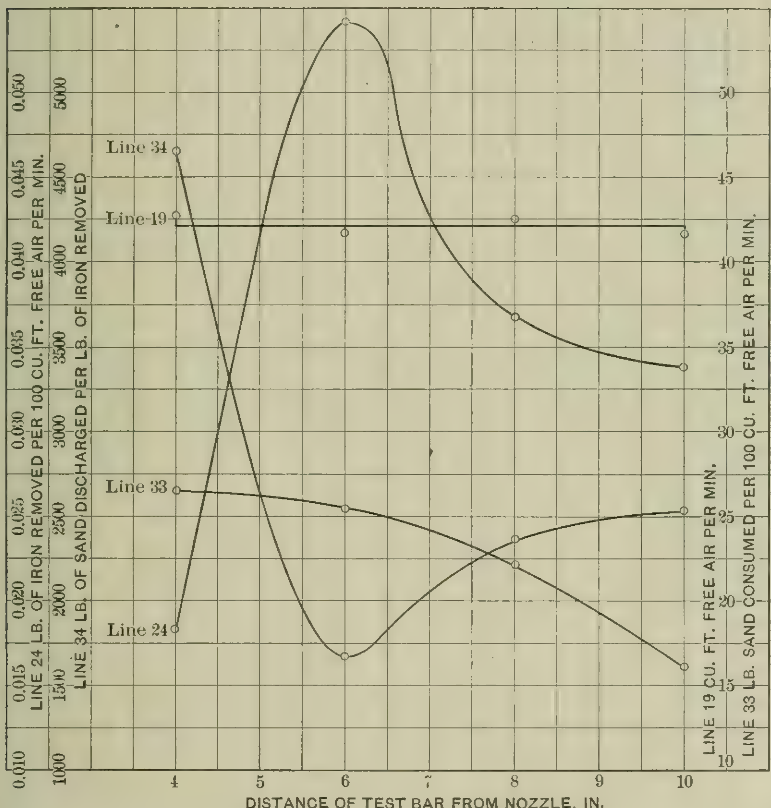

FIG. 9 RESULTS OF TESTS IN RELATION TO DISTANCE OF NOZZLE FROM WORK

sure, the variation in the effectiveness of the blast due to increase of pressure was obtained, with the nozzle set at 45 deg. and at 8 in. from the test bar.

12 In the second series of tests, a constant pressure of 60 lb. was

TABLE 1 TESTS OF SAND-BLASTING MACHINE.

		Pressure Variable					
1	Number of test	1	2	3	4	5	6
2	Diameter of nozzle, in.	$\frac{5}{16}$	$\frac{5}{16}$	$\frac{5}{16}$	$\frac{5}{16}$	$\frac{5}{16}$	$\frac{5}{16}$
3	Angle of blast, deg	45	45	45	45	45	45
4	Distance of nozzle from casting, in	8	8	8	8	8	8
5	Length of run, min	15	13	20	20	10	10
6	Air presssure at sand-blasting machine, lb.	20	30	40	50	60	70
7	Air pressure in line, lb., corrected	78.4	75.0	76.1	75.0	75.0	76.5
8	Barometric pressure, in. mercury	29.08	29.13	29.35	29.35	29.30	28.80
9	Temperature of air, deg. fahr	77.6	85.1	82.00	83.20	87.50	80.40
10	Pitotmeter reading, in. water	0.056	0.070	0.085	0.112	0.135	0.150
11	Velocity head, ft. water	0.0047	0.0058	0.0071	0.0093	0.0113	0.0125
12	Volume as free air of 1 cu. ft. of compressed air under actual conditions	5.796	5 508	5.607	5.527	5.483	5.648
13	Weight of 1 cu. ft. of water at temperature of air in line	62.25	62.18	62.21	62.20	62.16	62.23
14	Weight of 1 cu. ft. air at actual pressure and temperature	0.4679	0.4446	0.4526	0.4462	0.4427	0.4560
15	Head of compressed air equivalent to 1 ft. of head of water	133.0	139.9	137.4	139.4	140.4	136.5
16	Velocity head, ft. air	0.6253	0.8111	0.9758	1.296	1.567	1.706
17	Velocity in air line, ft. per sec	6.342	7.223	7.922	9.132	10.10	10.47
18	Cu. ft. compressed air per min. at line pressure and temperature	4.866	5.543	6.079	7.007	7.752	8.038
19	Equivalent free air, cu. ft. per min	28.21	30.53	34.09	38.73	42.51	45.40
20	Weight of test bar before blasting, lb	44.5469	41.3906	36.4531	41.6094	41.3125	28.7031
21	Weight of test bar after blasting, lb	44.4765	41.3125	36.2969	41.3906	41.1563	28.5000
22	Iron removed, lb	0.0704	0.0781	0.1562	0.2188	0.1562	0.2031
23	Iron removed, lb. per min	0.00469	0.00601	0.00781	0.01094	0.01562	0.02031
24	Iron removed, lb. per 100 cu. ft. of free air flowing per min	0.01663	0.01969	0.02291	0.02825	0.03675	0.04473
25	Sand discharged, lb	255 0	262.0	512.0	631.0	369.0	415.0
26	Sand discharged, lb. per min	17.0	20.2	25.6	31.5	36.9	41.5
27	Sand discharged, lb. per 100 cu. ft. of free air flowing per min	60.27	66.19	75.10	81.34	86.81	91.41
28	Usable sand remaining, lb	226.0	230.0	420.0	504.0	275.0	293.0
29	Usable sand remaining, lb. per min	15.1	17.7	21.0	25.2	27.5	29.3
30	Usable sand remaining, per cent	88.6	87.8	82.0	80.0	74.5	70.6
31	Sand consumed, lb	29.0	32.0	92.0	127.0	94.0	122.0
32	Sand consumed, lb. per min	1.93	2.46	4 60	6.35	9.40	12.20
33	Sand consumed, lb. per 100 cu. ft. of free air flowing per min	6.843	8.059	13.50	16.40	22.11	26.87
34	Sand discharged per lb. of iron removed, lb	3625.0	3361.0	3278.0	2879.0	2362.0	2043.0

Lines 6 and 7 give corrected gage readings.

Line 12 is obtained from the characteristic equation for perfect gases $V_1 = \frac{492}{14.7} \times \frac{P}{T}$, by taking the absolute pressures and temperatures corresponding to the readings given on Lines 7 and 9.

Line 13 is taken from p. 688 of Kent's Pocket Book for the temperatures given on Line 9.

Line 14 = Line 12 × weight of 1 cu. ft. free air.

Line 15 = $\frac{\text{Line 13}}{\text{Line 11}}$

Line 16 = Line 15 × Line 11

Line 17 = $8.02 \sqrt{\text{Line 16}}$

Line 18 = Line 17 × net area of pipe in sq. ft. × coefficient of discharge × 60

Line 19 = Line 18 × Line 12

Line 23 = $\frac{\text{Line 22}}{\text{Line 5}}$

Line 24 = $\frac{100 \text{ (Line 23)}}{\text{Line 19}}$

COLLECTED DATA AND CALCULATED RESULTS

Angle Variable						Distance Variable		
7	8	9	10	11	12	13	14	7.1
$\frac{5}{16}$	$\frac{5}{16}$	$\frac{5}{16}$	$\frac{5}{16}$	$\frac{5}{16}$	$\frac{5}{16}$	$\frac{5}{16}$	$\frac{5}{16}$	$\frac{5}{16}$
30	45	60	90	45	45	45	45	30
8	8	8	8	4	6	8	10	8
8	10	10	10	10	9	10	10	10
60	60	60	60	60	60	60	60	60
78.1	75.0	77.0	79.0	78.4	77.7	75.0	77.0	77.8
29.13	29.30	29.20	29.20	20.08	29.30	29.30	29.08	29.30
81.60	87.50	78.10	80.15	78.97	89.66	87.50	77.94	79.44
0.140	0.135	0.154	0.140	0.130	0.127	0.135	0.125	0.208
0.0117	0.0113	0.0128	0.0117	0.0108	0.0106	0.0113	0.0104	0.0173
5.735	5.483	5.704	5.806	5.781	5.626	5.483	5.705	5.739
62.21	62.16	62.25	62.23	62.24	62.13	62.16	62.25	62.24
0.4630	0.4427	0.4604	0.4687	0.4667	0.4542	0.4427	0.4606	0.4633
134.4	140.4	135.2	132.8	133.04	136.8	140.4	135.2	134.3
1.572	1.587	1.730	1.553	1.440	1.450	1.587	1.406	2.324
10.06	10.10	10.55	9.996	9.625	9.657	10.10	9.508	12.23
7.717	7.752	8.096	7.670	7.386	7.411	7.752	7.296	9.382
44.25	42.51	46.18	44.53	42.70	41.69	42.51	41.63	53.84
36.5313	41.3125	51.6172	30.8437	44.2656	41.1250	41.3125	44.4062	41.4219
36.4375	41.1563	51.4531	30.7109	44.1875	40.9219	41.1563	44.2656	41.3125
0.0938	0.1562	0.1641	0.1328	0.0781	0.2031	0.1562	0.1406	0.1094
0.0117	0.01562	0.01641	0.01328	0.00781	0.02257	0.01562	0.01406	0.01094
0.02644	0.03675	0.03554	0.02982	0.01829	0.05413	0.03675	0.03378	0.0203
281.0	369.0	364.0	378.0	361.0	341.0	369.0	356.0	243.0
35.1	36.9	36.4	37.8	36.1	37.9	36.9	35.6	24.3
79.32	86.81	78.83	84.88	84.55	90.90	86.81	85.52	45.13
218.0	275.0	268.0	279.0	248.0	246.0	275.0	289.0	180.0
27.3	27.5	26.8	27.9	24.8	27.3	27.5	28.9	18.0
77.58	74.5	73.6	73.8	68.7	72.1	74.5	81.2	74.1
63.0	94.0	96.0	99.0	113.0	95.0	94.0	67.0	63.0
7.875	9.4	9.6	9.9	11.3	10.6	9.4	6.7	6.30
17.80	22.11	20.79	22.23	26.46	25.42	22.11	16.09	11.70
3000.0	2362.0	2218.0	2846.0	4642.0	1679.0	2362.0	2532.0	2221.0

$$\text{Line } 26 = \frac{\text{Line } 25}{\text{Line } 5}$$

$$\text{Line } 27 = \frac{100\ (\text{Line } 26)}{\text{Line } 19}$$

$$\text{Line } 29 = \frac{\text{Line } 28}{\text{Line } 5}$$

$$\text{Line } 30 = \frac{\text{Line } 29}{\text{Line } 26}$$

$$\text{Line } 32 = \frac{\text{Line } 31}{\text{Line } 5}$$

$$\text{Line } 33 = \frac{100\ (\text{Line } 32)}{\text{Line } 19}$$

$$\text{Line } 34 = \frac{\text{Line } 27}{\text{Line } 24}$$

maintained at the machine, and the nozzle set at 8 in. from the test bar. The angle was varied from 30 to 90 deg. The effectiveness of these angles of blast was in this way obtained.

13 In the third series of tests, the distance of the nozzle from the test piece was varied, the angle being set at 45 deg. and the air pressure maintained constant at 60 lb.

OBSERVATIONS

14 It was noted that with no sand flowing, the quantity of air flowing approximated the theoretical discharge for the nozzle. On turning on the sand, the quantity of air flowing immediately decreased; and when the sand was "on full," the amount of air discharged was only 40 to 50 per cent of the original quantity.

15 With constant air pressure and with the sand-controller lever in its "on full" position, on account of the variation in the openings of the sand and air ports of the machine, about 30 tests were required to be made in order to get even fairly concordant results for the pounds of sand discharged per 100 cu. ft. of free air flowing per minute, as shown on Line 27, Table 1. For constant pressure, variations in the pitotmeter readings were due to the variations in the sand flowing. As the quantity of sand decreased, the velocity and quantity of air increased, but the quantity of sand discharged per pound of iron removed also decreased. This can be seen by comparing the readings on Line 34 for tests 7 and 7*A*. It would seem that further experiments might prove that at other angles than 30 deg., and at other distances than 8 in., and at other pressures than 60 lb., less sand would be used per pound of iron removed if the sand-regulating valve was not open so much. This would make the energy of the individual grain of sand greater and its blasting effect larger. Furthermore, there would be less piling up of the sand on the surface being sand-blasted.

RESULTS

16 From these quantitative experiments on a cast-iron test bar for these three variables, within the limits used, the results as given in Table 1 and graphically shown in Figs. 7, 8 and 9, are as follows:

a For a constant distance of 8 in., and at a constant angle of 45 deg., between the nozzle and the test bar, the equivalent amount of free air delivered per minute, the iron removed, the sand discharged, and the sand used up per

100 cu. ft. of free air flowing per minute, vary directly with the pressure; the per cent of usable sand remaining, and the amount of sand discharged per lb. of iron removed vary inversely with the air pressure in the machine. (See Lines 19, 24, 27, 33, 30, and 34, Fig. 7.)

b With a constant pressure of 60 lb. in the machine, and a fixed distance of 8 in. from the nozzle to the test bar, the largest amount of metal was removed, and the least amount of sand was required to do it, when the angle between the nozzle and the surface of the work was from 40 to 60 deg. (See Lines 24 and 34, Fig. 8.)

c With a constant pressure of 60 lb. in the machine and a constant angle of 45 deg. between the nozzle and the surface of the test bar, the largest amount of metal was removed, and the least amount of sand was required to do it, when the distance from the nozzle to the work was about 6 in. (See Lines 24 and 34, Fig. 9.)

d With a constant pressure of 60 lb. and a fixed distance of 8 in. from the nozzle to the test bar, the amount of sand used up varies as the directness of the blast. (See Line 33, Table 1.)

e With a constant pressure of 60 lb., and a constant angle of 45 deg. between the nozzle and the test bar, the amount of sand used up varies inversely with the distance of the nozzle from the test bar. (See Line 33, Fig. 9.)

f For a constant angle of 45 deg., and a fixed distance of 8 in. between the nozzle and the test bar, twice as much metal was removed at 56 lb. pressure as at 20 lb.; at 64 lb. as at 30 lb.; and at 72 lb. pressure as at 40 lb. (See Line 24, Fig. 7.)

g With a constant pressure of 60 lb., and a constant distance of 8 in. between the nozzle and the test bar, over 20 per cent more metal was removed with the nozzle held at 45 deg. than at 90 deg. to the test bar.

h With a constant pressure of 60 lb., and a constant angle of 45 deg. between the nozzle and the test bar, 60 per cent more metal was removed when the nozzle was held at 6 in. than at 10 in. from the test bar.

CONCLUSIONS

17 Unless it can be shown that the extra cost of compressing one hour's supply of air, or 2760 cu. ft. of free air per hour (60 x 46 cu. ft. per minute for 72 lb. pressure, line 19 of Test 6) to a pressure of 72 lb. per sq. in. exceeds the cost of compressing two hours' supply of air, or 4090 cu. ft. of free air (2 x 60 x 34.09 cu. ft. per minute for 40 lb. pressure, line 19, Test 3) to 40 lb. by the cost of an hour of labor (25 cents), the higher pressures, delivered at an angle of about 45 deg., and at a distance of about 6 in. from the work, are to be preferred for the sand-blasting of cast iron.

18 Assuming that the actual horsepowers required to compress 1 cu. ft. of free air per minute to be 1.1 times that theoretically required, or 0.113 to compress to 40 lb. and 0.165 h.p. to compress to 72 lb. gage pressure,[1] the 34.09 cu. ft. per minute at 40 lb. will require 7.7 h.p-hr., and the 46 cu. ft. per minute at 72 lb. pressure will require 7.59 h.p-hr. It will thus be seen that the total power required to compress the necessary air to remove 1 lb. of iron is practically the same, irrespective of the air pressure.

19 If this should be true for other relative pressures and conditions, the total cost of sand-blasting equals the constant cost of compression per pound of iron removed, plus the sum of the time-costs of labor, interest and overhead charges; and therefore, the higher the pressure used, the less will be the time, labor, and total cost of removing a pound of material.

[1] Kent's Pocket Book, p. 606.

THE OHIO STATE UNIVERSITY BULLETIN

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The Bismuthate Method for Manganese and A New Method for the Determination of Vanadium

BY

DANA J. DEMOREST

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THE BISMUTHATE METHOD FOR MANGANESE.

By D. J. Demorest.

There seems to be considerable misapprehension as to the effect which chromium has upon the bismuthate method for manganese. Thus it has been stated that chromium affects the results for manganese by this method. If, however, the method is properly carried on, the chromium has no influence. It is true that the bismuthate oxidizes some of the chromium to chromic acid, and this is titrated along with the manganese if the manganese is titrated by adding an excess of ferrous sulphate and then titrating the excess with permanganate. This is not the proper way. If the permanganic acid is titrated directly with sodium arsenite until the pink color disappears, the chromic or vanadic acids which may be present do not interfere at all and the results are accurate.

To show this, the vanadium steel standard issued by the Bureau of Standards was analyzed for manganese with and without the addition of chromium. The Bureau gives 0.669 per cent. as the manganese in the steel. The following results were obtained.

Without adding chromium	With 3 per cent. chromium added as $K_2Cr_2O_7$.
0.666	0.669
0.666	0.666
0.666	0.671

Another steel was run in the same way obtaining:

0.468	0.468

The acid open-hearth steel standard issued by the Bureau of Standards, and for which the Bureau gives 0.407 as their average, and the average by the co-operative chemists as 0.412 was analyzed with and without 3 per cent. Cr. The results were 0.403 per cent. Mn without, and 0.405 per cent. Cr with 3 per cent. chromium. Another

sample gave 0.489 per cent. without addition of Cr or V and 0.488 per cent. with the addition of 3 per cent. Cr and 1½ per cent. V.

The method as used in this laboratory is as follows: One gram sample is dissolved in 45 c.c. of water and 15 c.c. HNO_3 (sp.gr. 1.42) and the solution boiled until nitrous fumes are gone. After cooling a little, some bismuthate is added, a little at a time, until the resulting permanganic acid or manganese dioxide persists after a few minutes' boiling. Now KNO_2 is added to dissolve the MnO_2 and the solution is boiled a few minutes to expel the nitrous fumes. It is then cooled to tap water temperature. When cold, bismuthate is added a little at a time, while the solution is shaken, until about ½ gram has been added. After settling a moment the solution is filtered through asbestos on glass wool (for speed) and the asbestos washed well. Then sodium arsenite is run in from a burette until the pink tinge just disappears. There should not be a brownish color at the end. If there is, it indicates insufficient acid.

The arsenite is made by adding to 2¼ g. As_2O_3 in a beaker a hot solution of Na_2CO_3 until the As_2O_3 dissolves. It is then diluted to 2½ liters.

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A NEW METHOD FOR THE DETERMINATION OF VANADIUM.

By D. J. Demorest.

The following method for the determination of vanadium in steel depends upon the selective oxidation of ferrous sulfate in the presence of vanadyl sulfate by means of manganese dioxide. The vanadyl sulfate is then titrated by adding an excess of permanganate, the excess permanganate being titrated by sodium arsenite.

This differential oxidizing action apparently contradicts the results of J. R. Cain, (Jour. Ind. and Eng. Chem., 3, 476, 1911) who found that both iron and vanadium are oxidized, but the reasons for this discrepancy are shown in the note which follows this paper.

The manganese dioxide should be sufficiently fine to pass through a 200 mesh sieve and yet should settle in a beaker of water in 30 seconds.

The process in detail is as follows: In a 500 c. c. flask a two-gram sample of the steel or iron is dissolved in a mixture of 30 c. c. of water and 12 c. c. concentrated H_2SO_4, with application of heat. Then one c. c. of HNO_3, (sp. gr. 1.42) is added cautiously to oxidize the iron and the solution is boiled for a few minutes to remove the nitrous fumes. Then the solution is diluted with 30 c. c. of water and a strong solution of $KMnO_4$ is added to completely oxidize all carbon etc., and the solution is boiled. If the permanganate or the resulting MnO_2 should disappear, not enough permanganate has been used, and more should be added. Now ferrous sulfate is added to reduce the MnO_2, $HMnO_4$, H_2CrO_4, and H_3VO_4, etc., and the solution is again boiled to remove any possible nitrous fumes. Then pure distilled water is added to make the volume about 250 c. c., $N/_{10}$ $KMnO_4$ is added until the solution is pink, and the solution is cooled to tap water temperature. Ferrous sulfate solution is added until all reducible compound including chromic and vanadic acids are reduced. Only enough ferrous sulfate should be added to be certain that there is a decided excess pres-

ent. A solution, one c. c. of which equals about .01 gm. of iron, is the one used. Now about one gm. of C. P. MnO_2 is added and the solution shaken vigorously. After two minutes a drop is tested with ferricyanide on a white plate to see if the iron is completely oxidized. It generally takes from four to six minutes. At the end of each minute the solution is tested for ferrous iron until none is present and the shaking is continued for about one-half minute longer. It should be noted that a bluish color will always be obtained in the presence of vanadyl sulfate after the the test drop has stood for a few seconds. The end should be taken when the the test does not show blue immediatly. The blue color which forms after a few seconds, even when there is no ferrous iron present, is due to the reduction of ferri-to-ferrocyanide by the vanadyl sulfate. One can become familiar with this end by adding a drop of ferric sulfate containing vanadyl sulfate to a drop of ferri-cyanide on a white plate.

The MnO_2 oxidizes the ferrous sulfate to ferric sulfate but does not oxidize the vanadyl sulfate $[V_2\ O_2\ (SO_4\ )]_2$. Then the MnO_2 is filtered off on an asbestos mat, using suction. From a burette a standard solution of $KMnO_4$ is added until a pink tinge persists in the solution, then one c. c. more is added and after one minute the excess permanganate is titraded with $Na_2\ AsO_3$ solution. The end point is very sharp. If at this point the operator is not satisfied with his titration, the excess arsenite may be oxidized with $KMnO_4$, ferrous sulfate again added, then oxidized with MnO_2 as before and the titration repeated, thus giving a check on the titration. A blank determination must be run on a vanadium-free steel, and the result deducted. The blank generally amounts to about .00075 gm. V. The time required is about one-half hour and the results are very satisfactory. In fact the accuracy is about that of a phosphorus determination.

The vanadium steel standard furnished by the Bureau of Standards was analyzed by the above method. The result of the Bureau chemists is .143% V. and the average of the co-operating chemists is .15% V. The writer obtains the following results, the average being .143%.

.140
.147
.143
.138
.147
.143

To further test the method, two-gram samples of vanadium-free steel with the addition of ferro-vanadium containing 0.00684 gm. of vanadium were analyzed. The results were 0.00680 and 0.00690 gm. V. Another sample with 0. 0342 gm. V. was analyzed, and 0.03422 gm. V. was found.

To test the effect of chromium on the method, the Bureau of Standards' sample above mentioned was analyzed with the addition of 0.100 gm. Cr. The results were .143% and .143% V., showing that chromium has no effect on the vanadium results. Scores of other determinations have been made, proving the accuracy of the method.

The $KMnO_4$ solution used equals 0.001 gm. iron per c.c., and the arsenite solution has the same strength. This makes the $KMnO_4$ equal 0.000917 gm. vanadium per c.c. The arsenite solution is made by dissolving about 2 ¼ gm. As_2O_3 in Na_2CO_3 solution and diluting to 2000 c.c.

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THE OHIO STATE UNIVERSITY BULLETIN

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THE ROAD BUILDING MATERIALS

OF

COSHOCTON COUNTY, OHIO

By F. H. Eno

BULLETIN NO. 7

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Fig. 1. Coshocton Road, Guernsey County, Ohio. 8 inch Water bound macadam, built by State Aid.

Fig. 2. Coshocton Road, Guernsey County, Ohio. Brick on concrete base, built by State Aid.

THE ROAD BUILDING MATERIALS OF COSHOCTON COUNTY, OHIO.

By F. H. Eno

Introduction

The sentiment for good roads is developing throughout the United States very rapidly. It is fostered by politicians, merchants, vehicle manufacturers, touring clubs and to some extent by farmers. The latter statement is made guardedly, for the large percentage of the farmers are not yet interested in good roads; however, in those parts of the country where the farmer *is* interested in good roads he is *actively* interested. In New York, New Jersey, Massachusetts and some parts of our own State, the farmer has become one of the strongest advocates of improved highways. There is no doubt a good reason for this if it be sought.

The Highway Commission Engineers of this State relate an incident in one of the counties where a farmer obstinately fought every move to improve a road past his farm. The road was improved, however, and within two years that farmer was in the engineer's office asking for a blank petition to circulate for extending the improved road. When asked why *he* wanted a petition, he replied "Well, I did all I could to prevent your improving the road past my farm. I was wrong. I want to make amends by securing a petition to extend the improvement another mile. It will do me no good but it will help my neighbors and they will thank me when it is done." He secured every property owner's signature in that mile.

This has been the universal effect wherever good improved roads have been constructed. A questionnaire was sent out to several counties of this State. To the question "How do the farmers feel toward

road improvements?" the replies were "favorably" or "very favorably" and similar replies.

The high cost of good roads and the rapid destruction or total failure of many improperly improved roads, have been the two factors which have produced the greatest objections to them.

Ignorance of the available materials for improving roads and the lack of knowledge how to properly construct them have been largely responsible for these two objections.

It is the aim of this bulletin to discuss the materials, which are available for improving roads, found in Coshocton County, and to present some simple but effective methods for using these materials so as to improve the roads at a reasonable first cost. The writer hopes to benefit in this way the farmers, merchants and all the residents of Coshocton County, and at the same time boost good roads.

The investigation of the road building materials of Coshocton County was carried on in 1910 by Mr. A. H. C. Shaw, senior civil engineering student at the University from that county, who took up this investigation as the subject of his thesis. Due credit should be given to Mr. Shaw for the gathering of much of the data from which this bulletin is prepared.

The Need For Improved Roads

That there is a need for better roads in any part of Ohio demands no argument; it is self-evident to any traveler who attempts a trip through any part of the State by any method, exclusive of railways. Coshocton County is no exception to the rule.

The extent of the need for improved roads is measured by at least three factors, population, business and condition of roads.

The larger the population, the greater the need. The greater amount of produce, mineral output and manufactured products to move, the greater the need. The character of the geological and physiographical features of the country, whether a clayey or sandy surface, and character of drainage will also largely determine the need.

Topography of the County

Coshocton County is rectangular in shape, approximately twenty by thirty miles in dimensions, and contains 558 square miles of territory.

It lies on a portion of the eastern Ohio plateau with elevations ranging from 700 to 1200 ft. above sea level. The hill tops are dome-like in shape, which is characteristic of the weathering of the sandy shales of that region.

4 a

Fig. 3. An Unimproved Road.

Fig. 4. An Improved Road. Euclid Road, Lake County, Ohio. Brick on gravel foundation, built by State Aid.

The county is drained by the Muskingum River and its tributaries, the Tuscarawas and the Walhonding rivers and Wills creek. The county is thus cut by three prominent valleys and one subordinate valley, each a mile or more in width, diverging from near the center of the county; the Walhonding valley, coming from the west; the Killbuck creek, from the north; the Tuscarawas, from the east; the Muskingum extending southward; while Wills creek skirts the southern boundary of the county.

The lower river bottoms are frequently overflowed and hence are composed chiefly of fine silt and river mud which may be moved, deposited or denuded from time to time. The upper bottom lands or second terrace, 40 or 50 feet above the rivers, have gently rolling surfaces and are composed of coarse gravelly loams, with occasional beds of pure gravel. Other sections are more clayey. The hill tops contain much clayey soil.

The general surface exposure geologically is the Pottsville and Allegheny lower productive coal measures, consisting of sandstones, shales, limestones, clays and coal strata. The decomposition of these produce the soils of the county. No marked difference in the physical properties of the soils is noted in passing from one rock formation to the other. The sandstones are mostly shaly and crush very easily. The limestones are gray or bluish black, usually in thin shaly layers, easily disintegrating under the weather. The admixture of shale in all the strata causes the decomposed rock or soil to be very clayey and to cut up in wet weather, forming abominably muddy roads.

Population

The population in the different townships runs from 19 to 45 per square mile, averaging 36.8 per square mile for the entire county. The total population of the county according to the 1910 census is 30,121, of which 9,600 are residents of the city of Coshocton. Most of the townships have only 25 square miles of area. The three of smallest population are, Mill Creek township with 426 persons, Pike, with 507 and Perry with 587 persons.

There are approximately, 3,700 families living in the rural districts of Coshocton County, representing a population of about 18,000 persons. This would represent about 4,000 children of school age.

Each township would have about 200 scholars. If one in each 20 were to attend a centralized High school for four townships located approximately at the common corner, this would mean about 40 scholars who would have to travel on an average about 4 miles each

way or 8 miles per day, making a total of 320 miles daily. For the entire county the daily High school travel for the rural districts would be about 1,700 miles.

If these conditions are to prevail as they should in every populous county in Ohio, it will be necessary to provide good roads. The time saved to the farmers in getting their children to and from school, the greater regularity in attendance, the saving of wear and tear on their animals and conveyances for this service, and the convenience and health of children and parents, all accumulate into a saving which represents many dollars that can not be definitely tabulated in an estimate.

Each township has from 40 to 60 miles of public roads or a total of 1169 miles in the county. Seventy-nine miles of this were improved up to January 1st, 1912. Twenty miles of improved road in each township or 440 miles in the county would put every section of land in the county within reasonable distance of a good road. This is not too much to expect to have done in the near future. Many of the counties in the State have already far exceeded that proportion.

Allen county has 725 miles macadamized and gravelled out of 897 miles of public roads. Butler county has 708 miles out of 814. Cuyahoga county has 116 miles of brick paved roads out of 601 miles of highways. Montgomery has 952 miles of macadam and gravel out of a total of 985 miles of roads. Warren county has 667 miles of improved roadways out of 779, and many other counties are equally well improved.

Agricultural Products

According to the U. S. Census reports for 1910, Coshocton County farmers produced 36,500 tons of corn, 11,900 tons of wheat, 5,300 tons of oats, 5,000 tons of potatoes, and 53,800 tons of hay, a total of 112,000 tons of produce. It seems safe to assume that more than 40,000 tons of this was moved to shipping centers. A map of the county shows that the average haul would be about 3½ miles, as the four railroads divide the county into 6 divisions, in two of which the maximum haul is 6 miles, in three of them it is 7 miles, and in one division it is 8 miles. On mud roads the produce can be hauled only at certain seasons of the year and at those periods, not over 1½ tons at a load. If the farmer loads the night before, he can begin hauling at 7 a. m. and by working 12 hours, allowing his team to feed while he loads the second load, and not losing any time until 7 p. m., he can haul 3 loads over the average haul on mud roads.

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Fig. 5. Quaker City and Salesville Road, Guernsey County, Ohio, before improvement.

Fig. 6. Quaker City and Salesville Road. Guernsey County, Ohio, 8 inch Water Bound Macadam, built by State Aid.

That makes $4\frac{1}{2}$ tons for one very heavy day's work, of 21 miles.

Mining and manufacturing interests have not been considered, but if the manufactured products in Coshocton County are to the population as those products in Ohio are to the State's population, then there should be one-one hundred and sixtieth part of $960,000,000 or $6,000,000 of manufactured products, annually produced in the county. This will require some transportation other than rail.

The Benefits of Improved Roads

Assuming that of the 440 miles suggested in a previous paragraph for immediate improvement, 300 miles were to be improved with gravel, 100 miles with limestone macadam and 40 miles with bituminous macadam of some sort, at the average prices noted elsewhere in this bulletin, the total cost of such improvement would be about $1,460,000, or equal to $4.10 per acre over the whole county.

Improved roads increase the value of farm lands as indicated by increased rental values, actual land sales, and the evidence given by the farmers themselves. Professor W. C. Latta of Purdue University, Indiana, sent out a questionnaire among the farmers of northern Indiana, a number of years ago, and received quite a number of replies from which he concluded that the average selling price of land due to the existing improved roads, had been increased about $6.48 per acre. The farmers judge that if *all* the roads were improved, land values would be increased on an average of $9 per acre. They estimated also the average annual loss due to poor roads at 76 cents per acre which at 6 per cent represented a depreciation value of $12.67 per acre due to mud roads.

Another inquiry carried on by the Office of Road Inquiry at Washington D. C. secured replies that indicated increased values ranging from $5 to $20 per acre. Real Estate men in Franklin county claim from $6 to $20 per acre. They claim rentals are increased from one to two dollars per acre, equivalent to $16 to $20 per acre if interest is figured at 6 percent per annum. Assuming one half of the land in the county would be so increased in value by improving the roads suggested, and assuming the increase to be nearly minimum or $6 per acre, this would mean an increased land value of $1,050,000 for the county.

Teams with drivers are worth from $4.00 to $4.50 per day almost any place in Ohio. The farmer can hardly afford to charge himself less than that when he can get it elsewhere in the county, but assume that he charges only $3.50 per day for each team against his hauling account. Assume as previously stated that he hauls only 3 loads of $1\frac{1}{2}$ tons each to market over $3\frac{1}{2}$ miles of mud roads, then it will cost

him $3.50 divided by 3 x 1½ x 3½ which equals 22 cents per ton mile. When the roads are improved, he can haul twice as much in from one to two hours less time, which will reduce the cost to about 11 cents per ton mile, thus saving 11 cents per ton mile. Improved roads not only mean this saving in cost of hauling but permits the farmer to fit his convenience and the market more readily.

Assuming the previous estimate of 40,000 tons of produce to be moved 3½ miles to be correct, good roads would save the farmers of Coshocton County 11 cents x 40,000 x 3½ or $15,400 annually. This sum capitalized at 5 per cent equals $308,000, which the farmer can afford to put into good roads annually.

To sum up some of the benefits in brief form:— If Coshocton County should decide to improve the 440 miles of road suggested above, at a cost of about $1,460,000, the farm lands in the county would probably be increased in value at least $ 1,050 000.

The farmers would save at least $15,400 in hauling, annually, which is equivalent to a capitalization value of $308,000.

Manufactured products and other commercial interests would probably save quite a material sum which we have no positive method of estimating.

Wear and tear on vehichles and harness, animals and persons would be materially lessened and school expenses reduced thus adding another saving which cannot be easily estimated.

These four items alone represent at the lowest estimate a value of $1,360,000 saved to the farmers of the county by improved roads to offset the cost of the improvement.

Add to these facts such other benefits as the following.

The farmer's market is extended over a longer time in the year; he can reach his market over greater distances with greater ease; he presents his perishable produce in better shape, receiving a higher price for it; his children have better school facilities; he is better served by the rural free delivery.

The city tradesmen receive increased patronage from greater distances; pleasure seekers and touring clubs receive greater pleasure; country churches are helped.

Social life on the farm and in the villages will be improved; and property values increased.

Road Materials

Paving brick, concrete, crushed stone of various kinds, limestone, trap rock, granite, sandstone, chert, crushed gravel, bank gravel,

slag, sand and loam mixed with various bituminius such as crude oils, coal tar and asphalts, oyster shells, coal slack etc., are used to make good roads or to improve them to some extent at least. Some of these materials are too expensive for some locations while others are only makeshifts at best.

The choice of the material for any particular stretch of road will depend upon, first, the character of traffic it must sustain, second the taxable valuation of the assessable property, third, the most available suitable material.

To illustrate, it would be next to useless to use a light, rather clean bank sand on a road for heavy auto travel when good limestone or traprock could be secured within a reasonable haul. Even then the trap or limestone macadam should be well bound with one of the bituminous binders. On the other hand, where farm land is not worth over $10 to $20 per acre for long distances, it would be almost confiscatory to construct a road that would cost $5,000 to $10,000 a mile, as would a first class water-bound or bituminous bound macadam road, unless the demand was sufficiently great so that the State or other benefited portions of the county would pay one half to three quarters of the expense.

Where auto and horse vehicle travel is heavy as it usually is around the larger cities, brick block, concrete, and bituminous bound macadams are the pavements to be selected. Property values will nearly always warrant the expenses under such circumstances. Cuyahoga County is an example. In that county 116 miles of brick paved roads have been constructed. Hamilton, Franklin, Lucas and Montgomery counties might profit by that example. In less populous districts there will not be such heavy traffic nor as many autos hence cheaper roads of oiled water-bound macadam, plain water-bound macadam, or well constructed and well rolled gravel will be quite satisfactory. While in the more sparsely settled and less traveled portions of the State thinner macadam roads, ordinary gravel roads or well graded earth roads, oiled, harrowed and rolled, will supply very satisfactory lines of communication.

How to Build Good Roads

The building of good roads requires intelligent use of any of these materials. To use them carelessly or with no knowledge of how to use them is worse than wasting them, because the taxpayers are defrauded, the road will not wear or give satisfaction, and the materials out of which the road was constructed are discredited.

Drainage

The first and prime essential of any good road is drainage, surface, sub-surface and side drainage. When finished, the road must shed water. To do this the surface must be crowned from 3/8 to 3/4 of an inch to the foot depending upon the wearing surface and must have an impervious or waterproof covering. There must be an un-impeded slope from the crown to the gutter or to the side ditch. The gutters or side ditches should have at least 4/10 of a foot fall per 100 feet, and if they are earthen ditches, they should have 1/2 foot per 100 feet, and free drainage at frequent intervals into natural creeks or channels.

In order to drain away the sub-surface water and prevent it from softening the foundation thus permitting the paving material to be engulfed during the spring thaws, it is well to have one or in some cases two lines of tile running parallel with the road and laid from 2 to 4 feet deep and about 2 to 6 feet away from the edge of the improved roadway.

The second essential, which is an essential of any structure, is a good foundation and this is especially required for roads where the loads are concentrated on such small areas. For plain earth roads, this is secured by good drainage. Keep the road crowned up well by the use of the split log or drag scraper, as explained in Prof. Ramsower's Bulletin,† or in the U. S. Agricultural Bulletins,‡ taking care to remove all vegetable and organic matter of any consequence from the material graded to the center of the road and to do the grading at times when the road is not a mass of dust or mud. For earth roads it is particularly necessary to keep the side drainage open and in order at all times. In many localities sub-drainage is necessary to keep the soil dry and solid.

Upon the earth road just described, the next cheapest improvement can be built, namely a graveled road. Upon a well shaped, well drained, well graded earth road spread 4 inches of bank gravel which carries about 12 to 18 per cent clayey material or loam in it. If this loamy material is impregnated with iron so as to give the mass a dark reddish appearance all the better, for it will bind the gravel together acting as a cement and make the gravel roadbed water tight.

The graveled way can be made 8 to 16 feet wide but rather than make it wider than 16 feet, it would be more economical to increase the depth in order to secure a more durable roadway. A first class

†Agricultural College Extension Bul. No. 9-May 11, 1911. Published by the Ohio State University.

‡Farmer's Bulletin No. 321-U. S. Dept of Agriculture.

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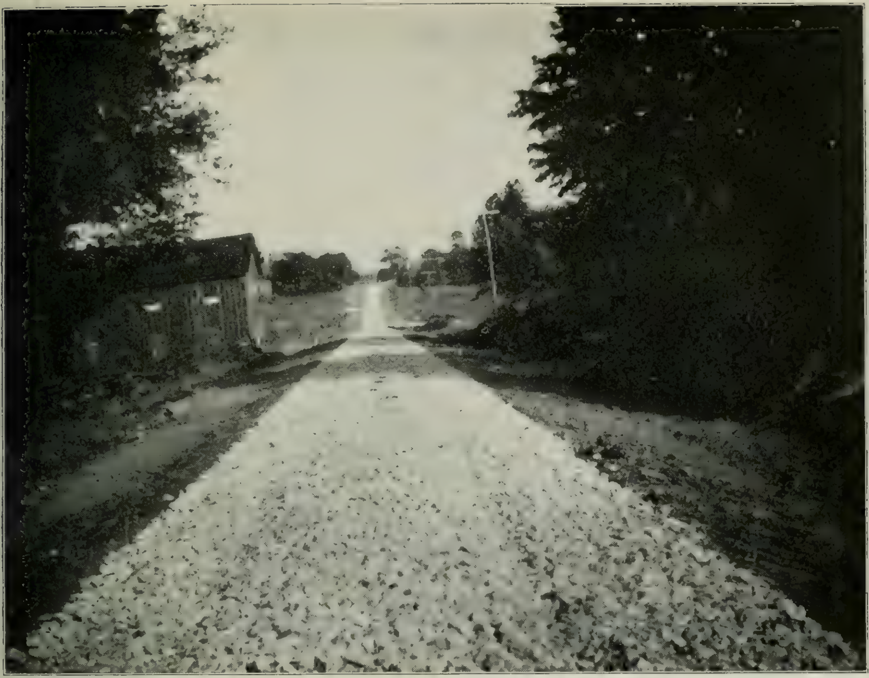

Fig. 7. Spencer School House Road, Geauga County, Ohio.
First course of macadam, built by State Aid.

Fig. 8. Spencer School House Road, Geauga County, Ohio. 9 inch finished macadam road, built by State Aid.

graveled road should be 10 to 14 inches deep. In spreading the gravel the coarser stones and pebbles should be raked ahead on the roadbed and the finer gravel spread over them.

The cost of renting or in many cases of buying a roller and rolling the graveled road will be more than returned to the county by the greater comfort and convenience in using the roads and the increased life and traffic-carrying power of the rolled road. Where the road is to be compacted by traffic, it will pay to shape the road frequently with a split log or other drag until it has become thoroughly compacted.

Where the trench method of road building is adopted, it is well to construct capes or wings of the material extending over the edges of the trench from 1½ to 2 feet in order to carry the water away from the foundation trench.

These capes may be 3 to 5 inches thick over the edge of the trench in order to give sufficient thickness to prevent the percolation of water and the cutting through under traffic.

Because macadam roads are much more expensive than gravel roads in first cost, they should be built very much more carefully. The same methods will apply no matter what material is used. The materials in their order of excellence are—trap rock, tough granite, chert, tough limestone, ordinary limestone, slag and tough sandstone.

The road may be built by either the surface or trench construction but preferably by the semi-trench method. The roadway should be graded as shown in Fig. (9) and the sub-grade well rolled or compacted. The stone should be crushed and screened into at least three

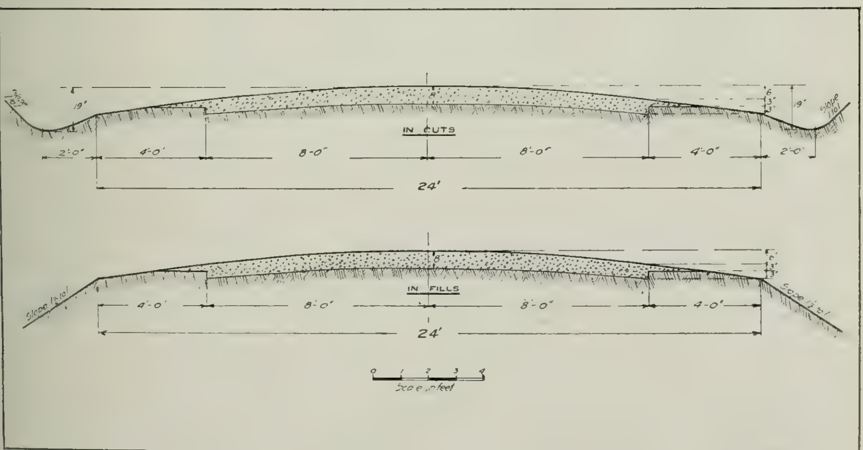

Fig. 9. Proposed Sections for Macadam Roads.

sizes, that which will pass through a half inch mesh, that which will pass a one and one-half inch mesh and be caught on a one half inch mesh, and that which will pass a 3 inch mesh and be caught on an inch and a half mesh. The road should be built in two or three distinct layers, depending on the final thickness. Use two layers for 6 to 9 inch roads and 3 layers for 9 to 12 inch roads.

In the bottom layer use the coarser stone, roll well and then sprinkle evenly over the surface a ½ to ¾ inch layer of screenings, roll once or twice dry, then flush well with water from a sprinkling wagon and roll until thoroughly compacted, sprinkling ahead of the roller from time to time. Upon this compacted layer spread the next layer of stone which should be of the medium size. Treat this layer the same as the first layer, rolling more thoroughly and using either a thin layer of bank gravel and limestone screenings or all bank gravel for the binding layer, depending upon whether the screenings of the crushed stone or the gravel give the best results as a binder. Never use an excess of binder but sufficient only to thoroughly fill the voids. Allow the road to dry out two or three days before permitting any heavy traffic upon it.

Very frequently it is found that a heavy bank gravel is better for a binder than the screening of the stone. Some gravel banks are overlaid or have running through them a stratum of dark rusty red clay mixed with gravel; this is usually an excellent material for binder as the iron gives cementing qualities and aids in making the road impervious. Cut the bank down, mixing this layer with about 3 or 4 times its mass of the regular bank gravel.

It is hardly worth while to use crushed stone for improving a a road unless a road roller and sprinkler are used and the road thoroughly compacted.

Where the roller cannot be used, it is about as well to depend upon the more readily packed and cheaper bank or river gravel to improve the roads.

Near the large towns and on the through roads where there may be heavy auto travel it will be necessary to oil the finished surface of all macadam roads with heavy asphaltic base oils or use some form of bituminous mixture to bind the top layer together.

There are several companies which prepare and furnish oil and tar products and asphalt which are valuable for laying dust and binding road surfaces together.

For dust laying and use on sandy soils the Standard Emulsify-

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Fig. 10. Medina Extension Road, Summit County, Ohio. Tar Macadam, Applying Tar, built by State Aid.

Fig. 11. Medina Extension Road, Summit County, Ohio. Tar Macadam, Finished, built by State Aid.

ing Road Oil and the Standard Non-asphaltic Road Oil used several times a season materially improve the roads. One third to two thirds of a gallon of these mixtures per square yard of surface is generally sufficient at each sprinkling.

These cost from four to five cents per gallon and for a 16-foot roadway will cost from $180 to $230 per mile when one half gallon per square yard is used.

For heavier work, that is for the binding of road materials together, the Standard Asphalt Road Oil or Standard Macadam asphalt binder are to be used.

The Asphalt Road Oil is known as Nos. 3, 4, 5, and 6 according as it contains 30, 40, 50 or 60% of asphaltum base in it. Nos. 3 and 4 can be used for ordinary earth roads while Nos. 5 and 6 are used for binding macadam roads. The cost of No. 5 is 9 to 10 cents per gallon. The cost of No. 6 is 10 to 11 cents per gallon.

The best method of using these oils is to put on a four inch layer of stone ranging in size from 1 inch to 2½ inches in diameter. Spread evenly and roll firmly, then heat the oil and apply it through flat nozzled cans or by tank cart sprinklers, applying from 1¼ to 1½ gallons per square yard. Sprinkle screenings or fine stone chips over this and thoroughly roll, the screening should be applied until all the oil is absorbed. *Standard macadam asphalt Binder, Liquid asphalt, Pioneer asphalt cement, Taroid, Tarvia, Ugite, etc., are all used in the same manner. Kentucky rock asphalt consists of a sandstone saturated with asphalt. When heated it becomes a sandy mixture with an asphaltic binder. It is heated and about one inch or 1½ inches spread over a solidly rolled crushed stone base, it is then thoroughly rolle- and is ready for traffic. It makes a road nearly as good as sheet asphalt.

Heavier traffic and more valuable property may demand a concrete or brick paved road. Concrete will probably be cheaper in first cost, but there is not enough experience with it, as yet, to prove its durability. It should be no more noisy, nor slippery than brick. When properly laid it should have about the same tractive resistance and

*The addresses of some of the companies furnishing these bitumens are as follows:
Barnett Mfg. Co., Cleveland, Ohio, handles Tarvia products.
Dolarway Paving Co., 95 Liberty St., N. Y. City, Bitumen Coated Concrete.
United Gas Improvement Co., Arch St., Philadelphia, "Ugite."
Standard Oil Co., 72 W. Adams St., Chicago—Various Asphalt Oil Products.
Indian Refining Co., Cincinnati, Ohio—"Liquid Asphalt."
Good Roads Improvement Co., Cincinnati, Ohio,—"Asphaltoilene"
Continental Bitumen Co., Toledo, Ohio,—"Carbo Via."
Wadsworth Stone & Paving Co., Pittsburg, Pa.—Kentucky Rock Asphalt.
American Asphaltum & Rubber Co., Chicago, Ill.,—Pioneer Asphalt Cement.

freedom from making dust or mud. When disintegration does set in it will probably go to pieces much more quickly.

The sub-grade should be properly shaped and rolled sufficiently to detect any soft places, which should be removed and the holes filled with gravel and compacted. The concrete should be of good, clean gravel or crushed stone in the proportions of 1 cement, 2½ sand, and 5 gravel. It will pay to have a good mixing machine for the concrete so as to get a uniform thorough mix. Lay the concrete somewhat wetter than a livery consistency and spade it into shape. Use a heavy wooden drag to rough float the surface so as to leave it with a good foot-hold for horses. It may be laid somewhat dryer and rolled with a steam road roller, but the laying must go on rapidly in order to give reasonable distances in which to operate the roller. Gravel or crushed gravel will probably produce the best wearing concrete.

In Cuyahoga County brick pavements have been extensively used. Wherever paving blocks are manufactured it might be worth while to consider brick pavements in connection with roads for heavy traffic, especially auto traffic. The sub-grade should be prepared as for a concrete road and 4 to 6 inches of concrete base put in as described above, except the proportions may be 1 cement, 4 sand and 8 screened gravel or stone. Upon this base 1½ inches of sand cushion coat is placed and the brick laid on this, rolled and grouted in flush with the surface, with a cement grout of 1 cement to 1½ mediumly fine sand. Stone or concrete curbs 5 inches thick and 18 inches deep should first be set along the edges of the brick roadway to keep the brick in place.

It is wasting money to lay brick pavement on rolled gravel or stone foundation for such foundations settle unevenly and the road becoming uneven, wears out rapidly. When a pavement upon a concrete foundation does wear out it is quite easily replaced at a reasonable cost and another 20 or 25 year period of life added to the roads.

THE COST IN GENERAL OF GOOD ROADS BASED ON WIDTH OF 16 FEET

Earth Roads

To pike or grade up an earth road and open side ditches will cost probably from $200 to $400 per mile. To drag it say 8 times a year will cost about $20 per mile to keep it in fair drainage shape, or about 3 cents an acre for the ordinary frontage.

Gravel Roads

The simplest gravel roads will cost for 16 foot improvements from $700 to $1,500 per mile, depending on the haul and the amount of grading done. This is for a thin covering of about 6 inches of gravel. When deeper layers of gravel are used, proportionately greater cost will ensue.

Permanent or carefully constructed gravel roads, 16 feet wide, and 9 inches to 12 inches thick, with well graded and rolled sub-grades and the gravel carefully rolled, will cost from $1,900 to $4,000, per mile where previous drainage has been provided—where new drainage is to be provided they will cost from $2,100 to $4,300 per mile, depending upon the grading necessary.

Macadam Roads

Water bound macadam roads constructed of limestone and screenings will cost from $4,000 to $6,500 per mile. The cost will vary, of course, with the distance the stone is hauled, and the care and work expended on sub-grade and rolling the stone.

Bituminous bound macadam will cost from $6,000 to $9,000 per mile.

Macadam bound with Kentucky rock asphalt, thoroughly rolled would make an excellent road for automobile traffic and would cost about $8,000 or $10,000 per mile.

Concrete Roads

Concrete composed of one part cement, two and one half parts sand and five parts crushed gravel or limestone will cost from $6,500 to $8,000 per mile for a bed 6 inches thick, and 16 feet wide.

Brick Pavement on Concrete Foundation

A fourteen foot brick pavement laid on concrete base, with stone curbing, will cost from $12,000 to $18,000 per mile, complete.

The Available Road Building Material of Coshocton County

Gravel, sandstone, and limestone are the surface formations which must furnish the largest part of the materials for road building in this county.

All the river valleys and Killbuck creek so far north as Helmick are abundantly supplied with both river and bank gravel. Even the small runs have a limited amount of inferior shaly gravel which will, to some extent, allay the mud if applied to the roads. Scattered fragments and ledges of sandstone are found on almost every hill. In the northeastern portion of the country there are persistent strata of shaly sandstone which have made rather durable, serviceable roads. In the eastern part of the county large masses of rather hard sandstone are scattered along the bases of the hills. There is less of it and the stone is softer as the western edge of the county is approached.

The limestone in the county occurs usually in thin strata, outcropping on the hillsides and most frequently covered too deeply to be economically quarried for road material. However, at a few points it can be successfully quarried, as at Mill creek bridge north of Coshocton and on the Selby farm west of Roscoe. At a point about a mile and a half northwest of Plainfield there is also an available outcropping of limestone.

No paving brick are manufactured in the county, although a paving block is made just east of the county at Newcomerstown; and good paving block can be secured at Zanesville, Canton, and Akron, and at many other towns not so near-by nor conveniently located for shipping purposes.

Cinder is occasionally used as a cheap gravel substitute but it powders up rather rapidly and makes a black dusty surface.

The refuse from coal mines, the slack and slate piles, known locally as "gob piles," have been used with some benefit upon the roads, around mines.

TESTS OF MATERIALS

In order to determine the relative value of the various materials, samples were collected from all the known or suspected available sources in the county and these were subjected to the standard tests of the U. S. Road Laboratory.

The tests were made in the State Highway Laboratory at the Ohio State University. It is the aim of these tests to determine how well

the various materials will withstand the probable wear they would be subjected to if placed in a road.

A road surface must withstand weathering, (rain, drouth, wind, frost) impact of horses' hoofs, abrasion from wheels, crushing under concentrated loads, and suction from automobile tires.

Briefly stated the tests are as follows:—

Abrasion and Impact Test

First, to determine the power of the material to withstand abrasion and impact. There are two tests for these properties—one for brick paving block, and one for broken stone and gravel. The paving blocks are placed in a rattler, similar to the casting rattler of a foundry, and rattled for about one hour with a mass of cast iron shot to abraid and beat it up. This is a severe test and probaly tests the block as much as 8 to 15 years' wear would do in an ordinary well traveled road. The impact of the horses' shoes and the abrasion of the wheels are both simulated in this test.

The rattler test is the principal test made upon paving brick. It detects the strength and weakness so thoroughly that no other test is needed. Some engineers require an absorption test to determine the amount of water which the brick will absorb, it being generally understood that a porous brick, which absorbs a large amount of water will disintegrate under frost action much more readily than a dense non-porous brick. A brick saturated with water will also abraid more rapidly under traffic. The porous brick will also abraid more rapidly in the rattler, hence the rattler test will have shown the experienced man the weakness.

The crushing strength of a brick that will stand the rattler test is so high that quality of a brick block does not need testing. The ordinary paving brick should stand 10,000 to 20,000 lbs. per square inch, while the greatest load drawn in the country and in most large cities, will not exceed 12 or 15 tons, which will not concentrate more than 4 tons upon a wheel whose minimum surface contact would probably not be less than 1½ to 2 square inches, or a load of 4,000 to 6,000 lbs. per square inch.

In testing broken stone and gravel for abrasion, a definite weight of the dry gravel or stone is rattled in a tumbling rattler without shot for about 5 hours at a uniform rate. The amount of abrasion is obtained and compared with the abrasion of other stone whose value as a road building material is known. In fact all the tests made give only comparative values.

The U. S. Goverment has been making such tests for years and keeping track of what the material does in actual practise until a fair comparison of the results of service has been obtained. The tests for abrasion are expressed both by the percentage of abrasion and by a French method of expression known as the "Coefficient of Abrasion." This Coefficient is equal to 40 divided by the per cent of abrasion. Thus a material that had 4% of its weight abraided away in the test would be reported as having 40 ÷ 4 or a coefficient of 10 under the French Method.

Cementation Test

The second test on crushed stone or gravel, known as the Cementation test, is one to determine its power to cement or bind the road surface into a waterproof homogeneous mass. Without this property the road surface will never become a smooth solid mass, but will ravel and be covered with loose rolling stone, will be open and porous, allowing water to enter and soften the subgrade and thus rapidly destroy the road. The stone or gravel is crushed and ground into a fine powder. This powder is mixed with water into a dough, made into small cylindrical shaped pieces which, after being properly dried, are tested by impact to determine the number of blows of a certain intensity required to break them. The average number of blows determines the position of the particular specimen in the scale of excellence required for a good binding material.

A particular stone or gravel may give excellent results as a binding material and yet be greatly lacking in that property necessary to withstand wear, or abrasion. It may have a hard, tough texture and withstand abrasion and impact and yet have no value as a binding material. A stone may be hard and withstand abrasion but lack toughness and hence be readily broken under impact. It may be tough and yet so soft that it abraids rapidly. A combination of hardness, toughness and cementing power are desirable.

Toughness Test

The third test is to determine toughness. A cylinder of the stone is cut out with a hollow core drill, the ends are ground off smooth and the cylinder subjected to impact tests of a definite weight dropped from regularly increasing heights upon the test piece. The number of blows indicates the heights in centimeters from which the weight was dropped when the cylinder broke. This being compared with the height required for a material of known good value in road work determines the relative value of the piece tested.

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Fig. 12 East Palestine Road, Columbiana County, Ohio, Brick Laid on Concrete Foundation, built by State Aid.

Slaking Test

The fourth test, known as *the slaking test*, is made by setting a cylinder similar to the ones used in the cementation test into water and noting the time it takes to slake down to mud. If it withstands the breaking down effect of the water one minute or more, it is considered good. The more rapidly it becomes mud, the more rapidly will the material produce mud upon the road. In withstanding the action of water it also indicates the power of the binder on the road to shed water and protect the foundation.

Absorption Test

The fifth test is the absorption test made to determine the probability of the stone's absorbing so much water that it will be broken and disintegrated by freezing.

Specific gravity and weight per cubic foot give another indication of the density of the stone; the denser the stone as a rule the better it will wear on the road.

The safe values assigned to the forgoing tests are as follows:

For Brick Block

The loss by abrasion should not exceed 24% of its weight. Various specifications call for from 20 to 24% as the limit. It is important that in the test the whole charge should show uniformity in abrasion. Blocks that vary largely individually, will not make a durable, even street pavement.

If the absorption test is made it is well to specify that shale brick shall not exceed 2% and fire clay brick not more than 4%.

Brick should also be uniform in size and shape.

For Stone or Gravel

The abrasion test has the following values:

	PER CENT ABRADED	FRENCH COEFFICIENT
Poor material will have	5–	8–
Medium " " "	4 to 3	10 to 13
Excellent " " "	2.9 to 2	14 to 20
Highly " " " "	2–	20+

Cementation tests below 10 are poor; from 10 to 25, fair; from 26 to 75, good; from 76 to 110 very good; above 110, excellent.

Tests for toughness running below 13 are poor; from 13 to 19, medium; and from 20 upwards, good.

TESTS OF COSHOCTON COUNTY MATERIALS

Samples of materials were collected from all known or suspected sources in the county and subjected to the standard road laboratory tests which have been briefly outlined above. The results of these tests are given in tables numbered one and two, arranged in the order of excellence, of each kind of material, as nearly as possible.

The location of these materials is shown on the accompanying map of the county, each quarry, pit, or bank being designated by a colored circle with the number of the sample placed within so that by referring from the map to the table and vice versa, the location, character and quality of the particular sample may be noted.

A description of the sample under the same number follows herewith:—

LIMESTONE

No. 1 A massive bluish black limestone, slightly fossiliferous, about 30 inches thick, which outcrops on the lands of John Artz, deceased, located near the center of Section II, Oxford Township. It lies on a level with the flood plane and is overlaid with about 15 feet of clayey gravel which itself is suitable for road purposes. The depth of covering precludes the use of this stone unless the gravel be first stripped and used for secondary roads, so that the stone may be freed for the first class roads.

This proved to be one of the best limestones tested.

No. 2 Sample No. 2 was taken from a limestone quarry opened in 1908 for the purpose of piking the Keene road from about one mile north of the Mill Creek bridge to the bridge at Coshocton. The quarry is about 50 ft. above the road at the east end of the Mill Creek bridge near the northwest corner of Tuscarawas Township. The stratum is about 7 feet thick, varying from thick black layers at the bottom to thin soft layers at the top. It lies just over No. 3 Cannel coal.

The sample tested out well.

The road above mentioned wore well on the section north of the quarry, but soon wore out on the section toward Coshocton. The trouble here seened to be a combination of poor construction and careless selection of material at the quarry.

No. 3 This sample was taken from a small ravine a few rods west of a concrete watering trough on the land of L. P. Wentz in

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Sample No.	From Township	Re	Toughness Two Cores	Remarks
1	Tuscarawas	1	6–7	Dark grey stone
2	Oxford	1	7–8	Gray-black
3	Adams	1	8–14	Blue-black
4	Linton	1	9–8	Almost black
5	Washington	1	7–6	Gray-black
6	Lafayette	1	8–9	Blue-grey Flinty
7	White Eyes	1	6–2	Gray-black

1	Clark	1	.....	Large per cent of granite
2	Oxford	1		Some hard material
3	Lafayette		... ..	Good binding material
4	Oxford		......	Large per cent of quartz
5	Bethlehem			Small amt. of hard material
6	Clark	1	... ..	Large amt. of limestone

1	Lafayette	1		Predominence of quartz & granite
2	Linton	1		Quartz pebble and Granite

1	Oxford	1	3–6	Red, brown, yellow
2	White Eyes	1	5–6	Light gray
3	Jackson	1	3–10	Gray-brown
4	Pike	1	3–3	Brownish yellow

+ L=Loam or fine 1

D=Stone dust or fi

TABLE No. 1.

Laboratory Tests on Limestone

Sample No.	From Township	Abrasion Value in 5 Kilograms: Revols.	Percent of water	French Coeff.	Cementing Value: Max.	Min.	Aver. of 5 briq.	Slaked in one min.	Water Absorbed in 48 Hours: Per cent	Pounds per cu. ft.	Spec. Grav.	Weight in lbs. per cu. foot	Toughness Two Cores	Remarks
1	Tuscarawas	13870	4.1	9.8	208	24	71.4	Slightly	0.38	0.69	2.62	163.5	6–7	Dark grey stone
2	Oxford	10525	3 8	10.5	70	49	60.8	No	0.71	1.19	2.67	166.5	7–8	Gray-black
3	Adams	10525	4.9	8.1	169	31	82.8	No	0.87	1.44	2.66	166.0	8–14	Blue-black
4	Linton	10140	5.0	8.0	64	25	48.6	No	0.49	0.80	2.61	163.0	9–8	Almost black
5	Washington	10000	4.8	8.3	55	28	36.8	No	0 52	0.84	2.58	161.1	7–6	Gray-black
6	Lafayette	10000	5.2	7.7	57	35	45.8	Readily	0 67	1.10	2.65	165.5	8–9	Blue-grey Flinty
7	White Eyes	13870	3.9	10.2	50	20	30.0	No	0.88	1.46	2.64	164.6	6–2	Gray-black

BANK GRAVEL

Sample No.	From Township	Revols.	Percent of water	French Coeff.	Max.	Min.	Aver. of 5 briq.	Slaked in one min.	Per cent	Pounds per cu. ft.	Spec. Grav.	Weight in lbs. per cu. foot	Toughness Two Cores	Remarks
1	Clark	1000	4.3	9.3	+L=441 D=18	223 15	339. 14.8	Slightly	2.38	3.76	2.53	157.9		Large per cent of granite
2	Oxford	10140	4.4	9.1	L=307 D=21	172 12	248. 16.	"	1.68	2.63	2.51	156.8		Some hard material
3	Lafayette				L=366 D= 3	228 [illegible]	301.8 2.4	Readily	3.06	4.85	2.54	158.4		Good binding material
4	Oxford				L=311 D= 6	84 4	174.6 4.8	Slightly	2.62	4.27	2.61	162.9		Large per cent of quartz
5	Bethlehem				L=165 D= 15	125 11	148.2 13.2	"	2.60	4.27	2.64	164.5		Small amt. of hard material
6	Clark	10000	7.7	5.2	L=136 D= 34	98 21	120.2 28.2	"	2.04	3.34	2.62	163.5		Large amt. of limestone

RIVER GRAVEL

Sample No.	From Township	Revols.	Percent of water	French Coeff.	Max.	Min.	Aver. of 5 briq.	Slaked in one min.	Per cent	Pounds per cu. ft.	Spec. Grav.	Weight in lbs. per cu. foot	Toughness Two Cores	Remarks
1	Lafayette	10140	2.8	14 1	L=5 D=10	4 8	4.2 9.2	Slightly No.	1.30	2.06	2.54	158.6		Predominence of quartz & granite
2	Linton	10140	3.9	10.3	L=14 D=24	9 17	13 6 19.8	Readily No.	1.65	2.61	2.54	158.5		Quartz pebble and Granite

SANDSTONE

Sample No.	From Township	Revols.	Percent of water	French Coeff.	Max.	Min.	Aver. of 5 briq.	Slaked in one min.	Per cent	Pounds per cu. ft.	Spec. Grav.	Weight in lbs. per cu. foot	Toughness Two Cores	Remarks
1	Oxford	10000	21.6	1.9	9	5	6.4	Readily	5.7	8.12	2.30	143.5	3–6	Red, brown, yellow
2	White Eyes	10000	20.6	1.9	4	3	3.8	"	4.9	7.32	2.37	147.8	5–6	Light gray
3	Jackson	10000	25.2	1.6	9	5	7.6	"	3.9	5.65	2.34	146.0	3–10	Gray-brown
4	Pike	10000	40.5	1.0	16	11	12.6	"	4.7	6.98	2.33	148.6	3–3	Brownish yellow

+ L=Loam or fine material in the gravel passing No. 100 sieve.
D=Stone dust or fine materials of abrasion " " " "

the northwest quarter of Section 19, Adams Township. It is a dark blue stone containing many fossils and seems to weather badly. It is heavily overtopped and cannot be economically quarried. While it abraids and weathers rather easily, it has the best cementing qualities of any limestone tested from Coshocton County. It is not known to have been used for roads.

No. 4 This sample was taken from a ledge of massive limestone which forms the bed of Bacon Run for more than a mile up stream from a 5 foot water fall, located just south of the Coshocton Plainfield road in the northeast part of Section 2, Linton Township. The stone is dark blue in color and is in layers a foot or more thick. It is overlaid with but a few feet of stripping and can be easily and cheaply quarried. It is lacking in all the desirable qualities. This stone has never been used on the roads.

No. 5 Sample No. 5 was taken from the lands of George Noland in the western part of Section 19, Washington Township. A stratum of this blue limestone runs through most of the hill tops of this township but it is usually so heavily overtopped as to make its recovery expensive. In the test it proved deficient in cementing value but was otherwise of average quality.

A short stretch of road south of Wakatomika was piked with it about 20 years ago, and, although no effort has since been made to maintain it, it is still firm, though uneven.

No. 6 From a shallow excavation in an abandoned road leading off from the West Lafayette and Plainfield roads, between the lands of Zad Ewing and Samuel Moore, sample No. 6 was secured. It is the eastern central part of Lafayette Township. It is known locally as "bastard limestone." It lies near Coal No. 6 and forms the highest terrace of the valley. The exposed ledge, as worked, is about 4 feet thick, composed of a cherty, fossiliferous limestone having a conchoidal fracture and occurring in layers from 2 to 6 inches thick.

The tests show this stone to be about average.

The quarry was opened in 1909 to supply material to pike the West Lafayette-Plainfield road. The formation covers about 10 acres and is topped with a clayey loam which varies from 8 to 30 inches in depth.

The pike, though uneven, seemed to be wearing well after one year of service. The unevenness was probably due to poor construction and no maintenance, rather than to inferior material. The cost per cubic yard on the completed road was $1.29.

No. 7 Sample No. 7 was taken from a 6 foot ledge of limestone located on Thos. Hamilton's farm about a half mile south of Fresno, White Eyes Township. It outcrops on the hillside about 100 feet above the bottom lands, and is composed of massive layers of flinty, bluish gray stone. It proved to be a very hard, durable stone but of inferior cementing qualities. It weathers well. The outcrop is limited and it is overtopped with such heavy stripping that its use would be doubtful economy.

It has never been used for road purposes.

GRAVEL

Bank Gravel

No. 1 Clark Township owns a large bank of gravel a half mile south of Blissfield. It is 25 feet high and varies in material from very coarse gravel at the bottom to a two foot streak of loam at the top. Streaks of clean, pure gravel appear in it.

The coarse material stood well in the abrasion test and the dust in the gravel yielded the highest cementation test of any gravel in the county.

This bank is the exposure of a high terrace of considerable extent. Roads improved with this material are hard and smooth.

No. 2 Oxford Towhship owns a small bank adjoining the lands of Lenox De Witt, in the northwest quarter of Section II. The coarse material stands abrasion well and the gravel dust has good cementing quality. This bank has been used for many years. The gravel packs well in the road and has been used with success on the roads in this county.

No. 3 In the southeast corner of Section 14, Clark Township, on the land of Eli Fox is the first important deposit of Drift gravel to be found, in descending the valley of the Killbuck Creek. At Helmick is a terrace of about 10 acres and farther back a higher one on less extent. The small exposure by the roadside shows a clean, loose material with a covering of about 3 feet of loam.

The coarse material seems to lack wearing value but is fairly high in cementing value.

So far it has not been used for road purposes, but if the 3 feet loam were cut down and mixed with the cleaner gravel it would make a very fair road material.

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TABLE No. 2.

Mechanical Analysis of the Gravels

Sample No.	From Township	Sieve Analysis						Specific Gravity	Weight per cu. ft.
		Caught on Nos.					Passing		
		2″	1½″	1″	½″	¼″	¼″		
1	Clark	3.0	7.0	5.9	21.1	24.4	37.8	2 53	157 9
2	Oxford	2.4	6.9	9 1	15.9	16.1	51.7	2.51	156.8
3	Clark	1.9	11.2	18.6	33.9	17.1	17.3	2.62	163.5
4	Lafayette	0.0	2.1	5.5	7.3	8.9	76.2	2.54	158.4
5	Oxford	5.3	2.9	4.5	13.1	22.5	51.6	2.61	162.9
6	Bethlehem	4.5	2.9	4 8	10 1	20.2	57.5	2.64	164.5
1	Lafayette	0 0	23.2	12.7	18.1	14.0	32.0	2 54	158.6
2	Linton	0.0	13.4	10.7	16.1	15.8	44.1	2.54	158.5

No. 4 The town of West Lafayette is laid out on a wide drift terrace. Sample No. 4 was taken out of an excavation in the center of the town, made for the foundation of a bank building.

The test shows it to be unusually high in cementation value. As only about 8% of it is coarser than ½ inch in diameter, it was impossible to get a sufficient amount from the sample taken, to make an abrasion test. It would undoubtedly average up with the other samples of gravel tested.

This material has been used for years upon the road in that vicinity and always with good results.

Because it is a fine gravel, the road surface becomes somewhat sloppy in the spring and cuts into dust to some extent in the summer, when not properly cared for; but when properly graded and repaired, the roads are excellent the whole year round. At one of the banks east of the village the gravel can be procured for 5 cents a load.

No. 5 No. 5 is a bank gravel found on the land of U. S. G. Emerson in the northwest quarter of Section 13, Oxford Township. It comes from a low ridge through which the road has been cut leaving the sides of the cut standing vertical. This is always a good indication in bank gravel, for it denotes a good binding quality. This material is so firm that picks are necessary to dislodge it.

The laboratory tests do not show it to be as good as the samples preceding, but excellent roads have been made for a generation with it. It cuts up into dust and mud rather readily when not kept crowned up properly, but when properly graded and drained, it makes good roads.

It may be obtained for 10 cents per load.

No. 6 About one half mile east of Metham, on the land of Ira Fox, in Bethlehem Township, is a small bank of gravel which is the chief supply of road materials in this township. It is taken from an extensive terrace.

It has medium cementing qualities but was not tested for abrasion values because it is too fine for a satisfactory test.

A small portion of clay or loam added to this gravel and a careful crowning of the road would probably produce fair roads.

River Gravel

No. 1 Gravel No. 1 was taken from the lands of Seth Shaw near the West Lafayette bridge over the Tuscarawas river. This is a river gravel and gave the *lowest percentage of abrasion of any material collected in the county.*

It is seriously lacking in cementing value and hence should be used in connection with a binder from some well selected bank gravel such as Bank gravel No. 1.

This gravel is found in considerable quantities all along the river as far north as Fresno and next to the bank gravel at West Lafayette is the best cheap material in the Township. It sells for 10 cents per load at the pit and costs 40 cents per mile for the haul.

No. 2 This gravel was obtained in the bed of Bacon Run on the lands of J. W. Fowler, Linton Township. The valley here is a broad terrace of drift, and from this point down stream an abundance of both bank and river gravel is available.

This gravel closely parallels the best of limestones in its laboratory tests. It closely resembles a bank gravel in action. It is used on about 3 miles of road in that vicinity and gives excellent results. In mid-winter when neighboring roads are almost impassable, these roads are hard and dry. The owner sells the gravel to the Township for 5 cents per load.

SANDSTONE

Although the sandstone of the county is soft and inferior to the limestone as a road material, its abundance and common occurence together with its widespread use as a road material in this section makes it desirable to devote some space to its description.

No. 1 This sandstone was picked up on the side of a hill on the lands of F. A. Richmond, a quarter of a mile northeast of Orange, Oxford Township. The hillsides in the vicinity are strewn with fragments of a comparatively hard, mottled brown stone containing traces of iron. The iron content accounts for the hardness and good wearing qualities of this stone.

This proved to be the best of the samples tested. Its abrasion of 21.6% shows how low in the scale of road building materials it is, and yet it can be economically used as a foundation for some better wearing material for the surface coat. It has a very low cementing value and this also requires that other material be added to bind it in place.

It has been used for road foundations for many years, and when properly drained and covered, it has been quite satisfactory for ordinary country traffic. At the time the sample was taken a 700 foot section of road, 12 feet wide and 12 inches thick was being constructed of sandstone spalls, broken up and compacted by hand. Two inches of

shaly gravel from the bed of a neighboring run was put on as a binder and top dressing. The contract price was 38.5 cents per lineal foot.

No. 2 This sandstone was picked up along the roadside about 2 miles south of Fresno on the lands of Martha Davis. It is similar to that which is strewn over the hillsides throughout the township, and of which the farmers are only too glad to be rid.

It gave the best abrasion test of all the sandstones but was very deficient in cementing value. All of the sandstone should be bound by some highly cementitious material, and should properly have a 2 to 4 inch coating of some durable wearing material on top to protect the sandstone which should only be called upon to act as a drainage and supporting material for the wearing surface.

No. 3 Sample No. 3 was picked up on the land of Elisha Compton, one half mile west of Roscoe in Jackson Township. Large fragments of this red and brown sandstone are scattered throughout this township.

This stone is softer than the preceding samples, losing 25.2% in the abrasion test. Where it has been used upon the roads it shows the same easy abrasion under traffic. Nevertheless, proper treatment of this local material would greatly improve the conditions of the roads in this township at a reasonably low cast.

No. 4 The last of the sandstone samples tested was the poorest of all. Forty per cent of it abrading under the standard test. It had a larger cementing value than any other of the sandstones. It is but little tougher than some maple sugar which it resembles in appearance.

The sample was collected from a shallow quarry on the land of Isaac Norris at the western edge of Section 12, Pike Township.

The stone lies about 75 feet above the floor of the valley and at the point above selected, has a few feet of covering soil. The stone can be had for the hauling. This stone is scattered pretty generally over the township.

A stretch of road just west of the quarry was piked with the rock from this place in the fall of 1910 and covered with roadside earth. Six months later, in the early spring, it seemed to be holding up well, notwithstanding its softness.

Suggestions for the Use of the Available Materials

As has been shown, the available materials in Coshocton County are limestone of low medium quality, bank and river gravel, some

of excellent quality and some of rather poor quality, sandstone of very poor wearing value and some shale and waste slack piles of small value.

Primary Roads

For the best developement of the county there should be some substantial smooth surfaced roads leading from the City of Coshocton to the large towns in adjoining counties. The most direct roads having reasonably good grades should be selected; such roads for instance as those leading from Coshocton through West Lafayette toward Dennison; from Coshocton northeasterly through Canal Lewis and Fresno toward New Philadelphia; along the Walhonding and Killbuck streams toward Millersburg; up the Walhonding, through New Castle and Esto toward Mt. Vernon; through Jackson and Bedford Townships, East Union and Bladensburg toward Utica and Columbus; and south along the valley of the Muskingum river towards Zanesville.

These should be the best paved roads in the county. It would be worth while to pave these about 14 feet wide with brick block. They would immediately attract a large amount of traffic which would center at Coshocton and thus be of great value to that city. If brick could not be afforded, then a bituminous bound macadam or a Kentucky Rock Asphalt surface road should certainly be constructed.

Any improvement of these roads must be done having in mind the wear of a rather heavy traffic. It will not pay to put in any cheap form of improvement or any material that will quickly go to pieces. These roads have a total length of from 90 to 100 miles.

The cost of these main roads will be from $12,000 to $18,000 a mile if paved with brick; from $7,500 to $10,000 per mile for Kentucky rock asphalt with macadam base; $6,500 to $8,500 per mile for Taroid, and from $4,500 to $6,500 per mile for a good macadam road treated with "Tarvia B."

The roads east and south are now largely improved with gravel. By the use of Standard Asphalt Road oil, Tarvia or Taroid, they might be made serviceable for two or three years or more before being entirely rebuilt.

Secondary Roads

Many of the roads leading back from the river roads into the country, may very properly be improved by the use of the bank or river gravels. While but few samples were selected for tests, these gravel deposits are frequent all along the four main valleys. Whenever the traffic may demand, these roads may be improved still farther by treating with Tarvia or where the limestone outcrops, the more

Fig. 13. Illustrating "Improved Roads" as constructed by Local Authorities in various Counties in Ohio.

Fig. 14. Illustrating "Improved Roads" as constructed by Local Authorities in various Counties in Ohio.

permanent macadam road may be constructed, using the gravel for a binding material.

Farther back from the rivers, the scattered sandstone may be used for the drainge and supporting foundation with a top layer of limestone or gravel hauled in from the more distant pits or quarries.

The extreme northwestern portion of the county seems to be without any local material. Here it may be necessary to ship material into Rochester or Walhonding stations on the T. W. V. and O. R. R. and freight it back to the interior roads.

Where the stone and gravel do not show sufficient binding value in their dusts, it will be well to go to the extra expense of hauling gravel from the banks which do show good binding values. The convenience to travel, and the increased life of the road will far more than compensate for added expense.

Bank gravels Nos. 1 and 2 are the very best for this purpose, while Nos. 3 and 5 are the next best.

The Life of the Various Roads

Gravel roads need constant maintenance. Roads 10 to 12 inches thick when carefully rolled and bound, and where they are shaped and rolled each spring after the frost leaves the ground, should last 8 or 10 years. When they become badly worn and rutted, they can be reshaped and 4 or 5 inches more of gravel added, rolled and made as good as new.

Good limestone roads, water bound and well rolled should stand ordinary country traffic for 10 or 15 years. They will not stand fast auto traffic without being bound with bituminous binders. With such binders when properly constructed they should wear, even under auto traffic, 10 to 12 years.

Sandstone if used for the top course will not last long in any reasonable condition. For foundation purposes when properly bound and protected with a good wearing surface, it should last many years.

Brick paved roads on concrete foundation should last for 20 to 30 years under ordinary country traffic.

The cost of the material delivered upon the road is such that it is scarcely worth while to build a gravel or macadam road and let traffic compact it. When traffic is depended upon to do the compacting, the road has to be continually shaped and raked in order to secure a crown that will shed water; otherwise it will soon become dished and rutted and so saturated with water as to be of little value. The use of a roller is about as cheap as the former method and it secures a com-

fortable smooth road for traffic at once rather than after a year or so, and largely increases the length of life of the road.

Conclusions

Coshocton County is not blessed with any very excellent road building material of a permanent value. However, by wisely selecting the best material at hand, and following approved methods of construction some very good roads may be secured at reasonable first cost.

A consistent effort to secure such roads throughout the county should be fostered. Township trustees would make themselves a good name by employing an experienced, practical engineer to plan and direct such improvements. Such an engineer would save many times his salary in advising the best grades, best materials, best methods of constructon, etc.

The care given to improved or even to earth roads to keep them shaped up for drainage, to keep ruts filled in and worn places repaired, repays the cost many fold. Engineers, township trustees and county commissioners cannot make themselves indispensable in any more effective manner than by such attention to the highways.

Farm values can be increased by means of constructing good roads probably more rapidly than in any other form of improvement open for this county.

Fig. 15. Illustrating "Graded Earth Road" as graded by Local Authorities in various Counties in Ohio.

Fig. 16. Illustrating "Improved Broken Stone Roads" as built by Local Authorities in various Counties in Ohio.

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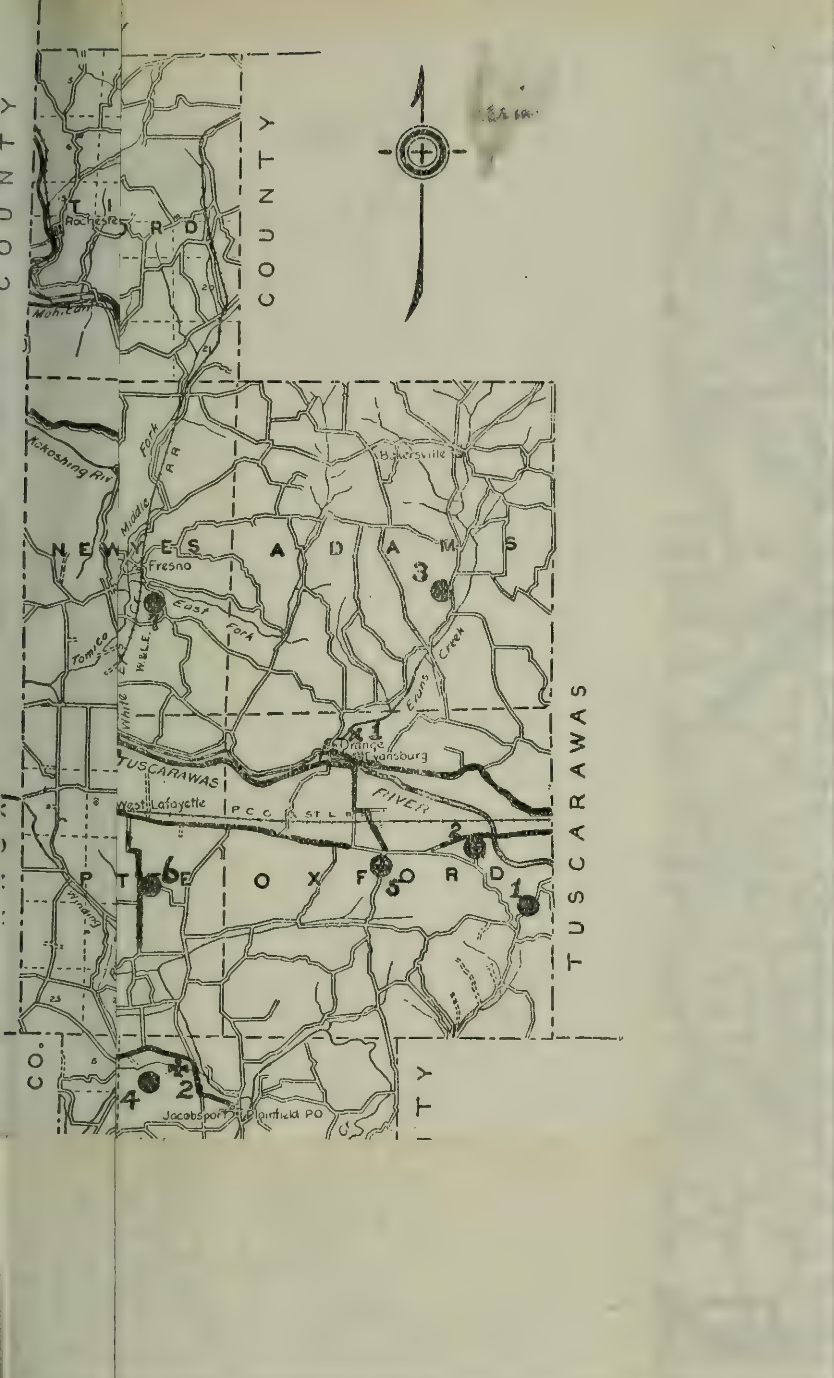
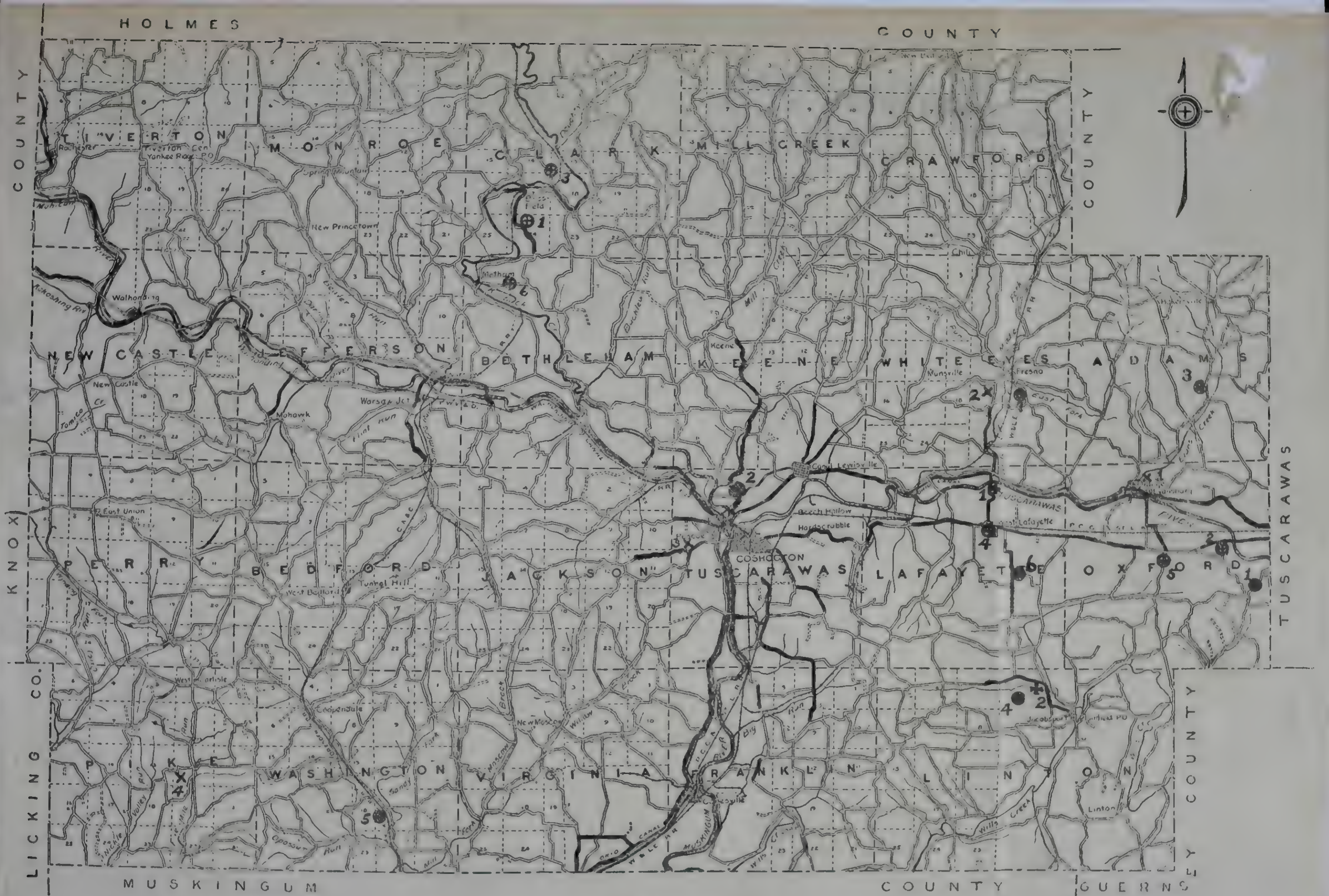


Columbus,
Ohio, under Act of Congress, July 16, 1894



LEGEND

LIMESTONE QUARRIES

BANK GRAVEL PITS

RIVER " "

SANDSTONE QUARRIES

GRAVEL ROADS

MACADAM ROADS

MAP OF

COSHOCTON COUNTY

Showing Location of Materials Suitable for Road Improvements.

0 1 2 3 4

SCALE OF MILES

THE OHIO STATE UNIVERSITY BULLETIN

VOL. XVI June, 1912 No. 40

STRESSES IN TALL BUILDINGS

BY

CYRUS A. MELICK

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STRESSES IN TALL BUILDINGS

AN INVESTIGATION OF THE STRESSES IN TALL STEEL BUILDINGS OF THE CAGE CONSTRUCTION TYPE WITH PORTAL BRACING

BY

CYRUS ALAN MELICK, D.C.E.

COLUMBUS, OHIO

1912

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INTRODUCTION.

This investigation has been undertaken with a three-fold purpose in view, as follows:

First, to develop a practicable mathematical solution of the stresses in tall buildings with portal bracing for all types of loadings, and, by its application, to determine the principal errors which exist in present methods of design.

Second, to endeavor by experiment on an existing structure to find by actual measurement the distribution and amount of stresses and distortions due to wind pressures, the only loading which can be practically varied on such a structure.

Third, to give in a final chapter a full and definite resumé of all findings and suggestions for designers as derived therefrom, so as to make the results of the investigation of value to the practicing engineer or architect without wasting his time in perusal of the body of the investigation, a proceeding which would, it is believed, be a discouraging one for a man who has been too busy in practical work to follow up closely a mathematical discussion.

This investigation consists, then, of a series of mathematical demonstrations, followed by an extensive series of applications and comparisons, and, finally, what is believed to be some very valuable conclusions offered in the last chapter, with references to the chapters from which the conclusions are drawn in case more detailed information is desired. Results have been shown graphically as far as possible, in addition to giving the actual tabular values. It is believed the investigation will be equally of value to the practical as well as to the theoretical man.

The mathematical treatment is based on an entirely elastic structure with what is believed to be an entire freedom from erroneous or doubtful assumptions.

This study has been made possible through the generosity of the late Professor Stillman W. Robinson, who established at the Ohio State University the Stillman W. Robinson Fellowship in Engineering. The writer has, during the years 1909–11, endeavored to

carry out the purpose Professor Robinson had in view in establishing the fellowship and now takes great pleasure in presenting to the Ohio State University and, through this institution, to the engineering profession generally, the results of a careful and diligent study of the stresses in tall buildings.

Acknowledgments are made and the author's sincere thanks extended as follows:

To the Ohio State University for financing the investigation.

To the Robinson Fellowship Committee for interest shown and advice given.

To Professor C. T. Morris, professor of structural engineering, for the interest shown, and advice and suggestions given throughout the work.

To Mr. J. Warren Smith, Section Director of the U. S. Weather Bureau.

To Mr. Frank L. Packard, architect, and his engineer, Mr. E. F. Babbitt, for furnishing plans and data.

To Mr. A. L. Fisher, superintendent of the structure used for the experiments.

Many others have, by suggestions and minor aid, been of assistance, and thanks are hereby extended to them collectively.

CYRUS A. MELICK.

COLUMBUS, OHIO,
June, 1911.

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NOTATION.

The following symbols are used throughout this investigation with the designations here given except in cases where there can be no confusion and in such cases a note is made of the exception.

Subscripts used in connection with the symbols below or any other symbols given later on always designate the floor in which the quantity occurs unless otherwise noted.

Exponents used in connection with the symbols below or any other symbols given later on always designate the member to which the symbol applies or the expression or equation in which it occurs unless otherwise noted. Thus I_3^A represents the moment of inertia of the third floor section of column A.

All the following quantities are in inch and pound units.

I = moment of inertia.
A = area of cross section.
E = modulus of elasticity.
b = distance center to center of columns.
c = story height measured between centers of gravity of girder flanges.
d = depth of floor girder, center to center of gravity of flanges.
V = axial compressive stress in a column.
H = axial compressive stress in a floor girder.
S = horizontal shear across a column section.
M = bending moment at foot of a column section ($x = o$).
s = axial unit stress.
s' = extreme fibre unit stress from bending only.
f = resultant extreme fibre unit stress.
r = minimum radius of gyration.
v = distance from neutral axis of column to the extreme fibre.
W = total load on any floor girder (considered as uniform).
w = floor load per lineal inch of girder.
P = concentrated load applied directly or indirectly to a column.
F = concentrated wind pressure for one story—considered as applied to the building at mid depth of the floor girders.

e = eccentricity of P.

Σ = summation of the terms immediately succeeding the symbol.

α = E times the axial shortening of a section of column included between mid depths of floor girders.

λ = E times the axial shortening of a floor girder in the length b.

δ = E times the deflection of the top of a column section ($x = c$) positive measured to the right.

Δ = E times the deflection of the left end of a floor girder ($x = b$) positive measured upwards.

C = E times the slope of the foot of a column section (inclination to the vertical). Positive measured to the right.

CF = point of contra-flexure.

x_0 = coordinate of point of contra-flexure in column.

FP = column fireproofing.

w_c = column weight per lineal foot.

Compressive stresses are indicated as (+) and tensile as (−).

Origins and axes of coordinates are taken as indicated on diagrams.

Other symbols will be introduced and explained as used.

CHAPTER I.

TYPES OF TALL BUILDING CONSTRUCTION.

The modern tall building is a structure well described by Freitag's definition in which this type of building is classified as "cage construction." He says:

"Cage construction, as exemplified by the best examples, consists of a steel framework with well-riveted beam and girder connections, efficiently spliced column joints and efficient wind bracing to secure its independent safety under all conditions of loading and exposure."

The walls of this type of building are of veneer construction and are carried, story by story, on the steel frame. All loads, of whatever nature, on such a structure are transmitted through the steel frame to the spread column footings and thence to a suitable foundation at safe unit pressures.

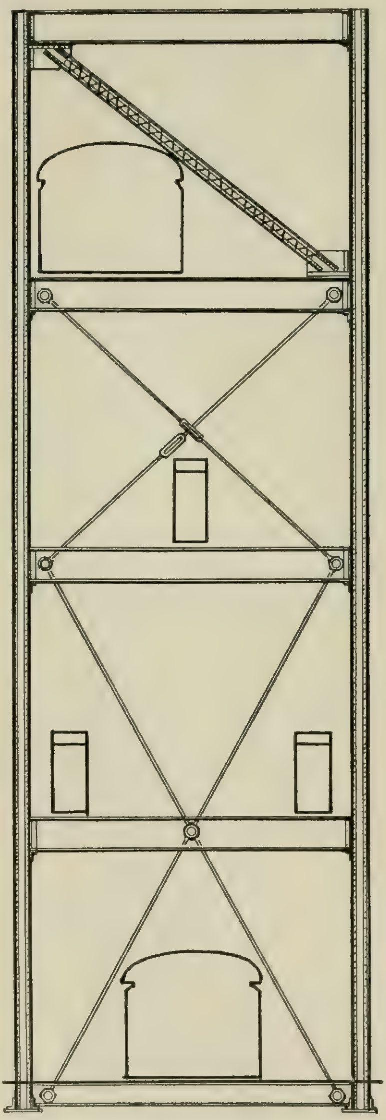
Classification of Modern Tall Buildings.

For the purposes of this investigation modern tall buildings may be considered as of two classes.

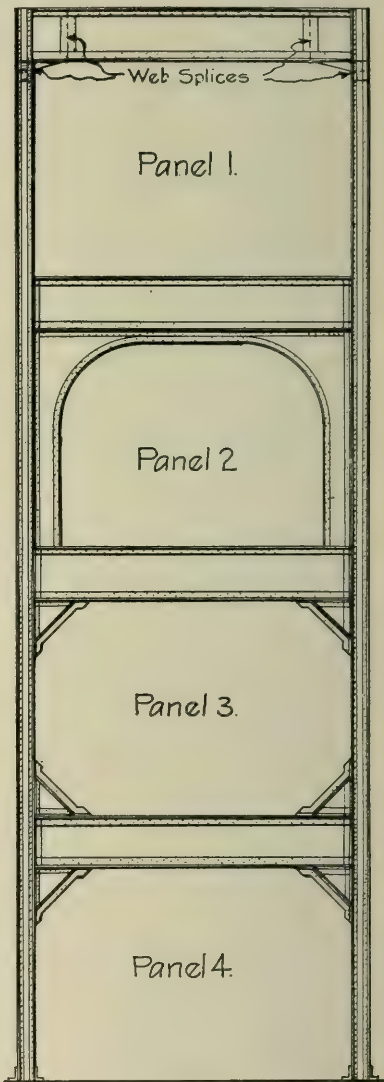
Class A comprises all those buildings in which diagonal members are placed in the transverse vertical column planes to transmit the wind pressure to the foundation. The columns in such buildings act as the chords of the wind trusses. All column stresses from wind on this class of buildings are axial and are statically determinate.

Class B comprises all those buildings in which, for architectural or practical reasons, no diagonal bracing can be permitted. This condition requires the use of portal bracing to take care of the wind pressure. The column stresses from wind pressure on this class of buildings are both axial and bending, and these stresses may form a very large percentage of the total stress in the column. All the stresses, from loads of any nature, in this class of structure are statically indeterminate.

Class A Buildings.—The fact that the wind stresses in a building



Diagonal Bracing.
FIG 1a



Portal Bracing.
FIG 1b.

of this class are statically determinate and the ease with which stresses may be computed and the design facilitated make this class a desirable structure. However, the diagonal bracing required imposes the condition that a comparatively thick partition be placed in the plane of the bracing for cover and protection of the steel. In the ordinary office building this condition divides the floor surface into sets of box-like suites, usually of the same shape and size. No large opening, no freedom in the selection of a position for an opening or corridor—in short, no effective architectural medium—can be used for joining adjacent suites through such a partition. Usually the doors must be small and either squarely in the center of a panel or on one side, according to the type of diagonal bracing used. Corridors must either extend along the wall, thus cutting off a great deal of window light from the offices, or down the center of a panel, creating a row of offices on each side of the hall. These limitations would often result in very shallow offices and sometimes in no direct communication between suites. By referring to Fig. 1, *a*, it will be seen that, from an architectural standpoint, single rigid diagonal bracing is preferable to the intersection systems of tension bars.

In practice the diagonal members frequently can not be designed so as to have the gravity axes of columns, girders and diagonal members meet in a common point and there result some bending stresses in the columns and girders. These are usually small and frequently neglected in the calculations. The floor girders in this class of buildings are usually shallow and, though the connections are riveted, they can not be said to be rigidly connected to the columns because the flanges are but very meagrely connected. In all calculations it is sufficiently accurate to consider them as connected to the columns by pins. The bending moments in the columns and girders, due to whatever rigidity these connections may have is thus neglected. As will appear from a later part of this investigation these stresses are certainly comparatively small. Buildings of Class *A* will receive but small consideration in the following pages.

Class B Buildings.—There are several styles of bracing used in this class of buildings; these are best comprehended by referring to Fig. 1, *b*.

"Panel 1" illustrates plain plate girder portal bracing in which the girders are made as deep as the design will permit and, as will be noticed, are *rigidly* fastened to the columns. *This can only be accomplished by properly connecting the flange angles as well as the web to the column.* This requirement is very rarely fulfilled in practice, because the large bending moments at connections require so many rivets to connect the flange angles that an extension of the web of the column is necessary to make the connections properly and this type of connection is difficult to make in the field. Panels 2, 3, and 4 show the common but very unsatisfactory method of making these connections.

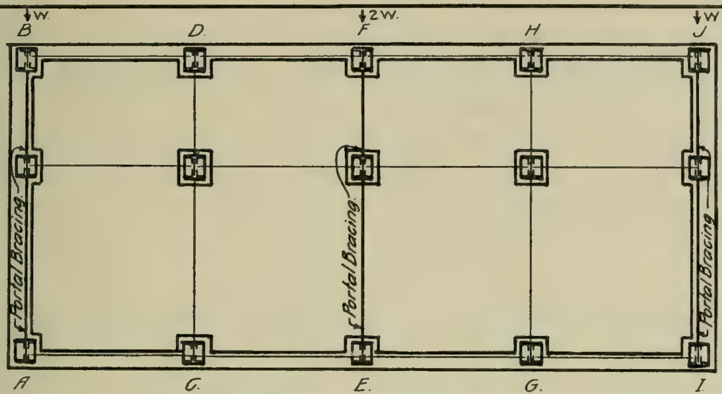
"Panel 2" illustrates a type of bracing which has been employed to some extent. It consists of a solid web plate, out of which the arches' opening is deducted, stiffened by angles bent to the curve of the opening. The bracing is field riveted by means of connection angles to the flanges of the columns and girders. This type of bracing is not so simple of analysis as plate girder portal bracing, it does not transfer stress directly to the neutral axes of columns and girders as a proper design should do, and the resistance of the girder connection itself is usually neglected in the calculations. This is not an economical form of bracing and has the added fault that some of the rivets in the connections are stressed in tension on the rivet heads.

"Panel 3" illustrates full knee braced plate girder portal bracing and this type, when the girders are properly connected, is undoubtedly the best and most economical of all types of portal bracing. The knee bracing may be merely one or two angles or, preferably, one or two angles and a solid triangular web as shown. In general no appreciable advantage is gained by making top and bottom knees of different depths. The knees should not be deep, as, in such case, the bottom knees will materially interfere with the floor space.

"Panel 4" is the same as "Panel 3" except for the omission of the bottom knees. Very heavy knees must here be used if any appreciable reduction in the bending stress at the foot of the column is to be effected.

The above statements concerning knee bracing will be fully verified in this investigation.

The arrangement of portal bracing, in plan, may be best discussed by reference to Fig. 2. Evidently sections AB and IJ are stiffened



Plan – Showing Location of Bracing
FIG. 2.

very materially by the rear and front walls respectively, while section EF has nothing to stiffen it but light partitions and even these are usually very much cut up by openings for doors, light, etc., and are subject to removal at any time. Therefore, if wind bracing is to be provided at section EF it should be stronger than that which is provided at sections AB and IJ irrespective of the fact that it gets twice as much wind load. If no bracing is placed in sections CD and GH then the wind coming to these sections must reach sections AB, EF, and IJ by being transferred through the floors alone, at each floor level. The girders on sections CD and GH, in such a case, need only be designed for floor loads and connected to the columns by ordinary methods and thus may well be considered as having hinged connections. It does not seem likely that the columns on these sections can receive any appreciable wind stress, either axial or bending. The other girders must be designed to act as wind bracing, in addition to supporting the floor, and the connecting columns must be proportioned for both axial and bending stresses from wind. The proper selection of sections for the economical disposition of wind bracing must remain a matter of judgment.

CHAPTER II.

DESIGN OF PORTAL BRACED BUILDINGS — RIGID GIRDERS.

This chapter is devoted to the design of plain, plate girder portal braced structures. A simple modification of the methods here given, required when knee braces are used, is given in Chapter XII.

General Method.

The following assumptions are involved in this discussion:

(*a*) That the floor-girders are absolutely rigid, *i. e.*, that they neither bend nor change in length when subjected to stress. Assuming the girders to be properly connected to the columns, this assumption implies that the columns are straight for the full depth of the girders and that all columns at floor levels have the same slopes and lateral deflections.

(*b*) The columns are assumed to bend under the action of lateral forces, but not to be affected in length by axial stresses. This implies that floor girders will always be horizontal and the columns vertical at floor levels.

(*c*) That the columns at their anchorages will always be maintained in a fixed vertical direction.

(*d*) That the elastic limit of the material will never be exceeded.

(*e*) That the column material shall be uniform throughout the structure.

(*f*) The increase of bending moment leverage due to the deflection of the columns is neglected.

(*g*) That the distribution of axial unit stresses among the several columns will be the same as if the building were considered as a solid beam, *i. e.*, that these unit stresses will vary directly as the distance from a neutral axis.

It is evident at a glance how impossible are assumptions *a* and *b*, and what a serious disagreement exists between these assumptions and assumption *g*. Nevertheless, the method based on these assumptions will, in later chapters, be shown to be sufficiently reliable

for taking care of wind pressures (with a slight exception) and the simplicity of the method has been the factor in commending it to the engineering profession.

SLOPES, BENDING STRESSES AND DEFLECTIONS OF COLUMNS.

Referring to Fig. 3, *b*, which is a general figure for any column section in the building:

At any point $P \equiv (x, y)$ on the elastic line of the column section there exists a bending moment $= M - Sx - Vy$ which, when the small term Vy is neglected, becomes $M - Sx$.

It is shown by the differential calculus that, sufficiently accurate for the purpose, the radius of curvature of the elastic line at any point is expressed as the reciprocal of d^2y/dx^2 at that point. From this and the experimentally verified principle that stress and the accompanying deformations are proportional within the elastic limit, it is further shown in mechanics that $EI(d^2y/dx^2) =$ the bending moment at P. I will not vary in the distance c and E is constant.

The differential equation of the elastic line of the column section is then written

$$E\frac{d^2y}{dx^2} = \frac{M}{I} - \frac{S}{I}x.$$

It will be noticed that the origin of coordinates is at the foot of the column section whose length is c. Integrating the above expression it is found that

$$E\frac{dy}{dx} = \frac{M}{I}X - \frac{S}{2I}x^2 + K$$

where K is a constant of integration. Integrating this expression it is found that

$$Ey = \frac{M}{2I}x^2 - \frac{S}{6I}x^3 + Kx + K'$$

where K' is also a constant of integration. But $dy/dx = 0$ when $x = 0$, hence $K = 0$ and therefore

$$E\frac{dy}{dx} = \frac{M}{I}x - \frac{S}{2I}x^2.$$

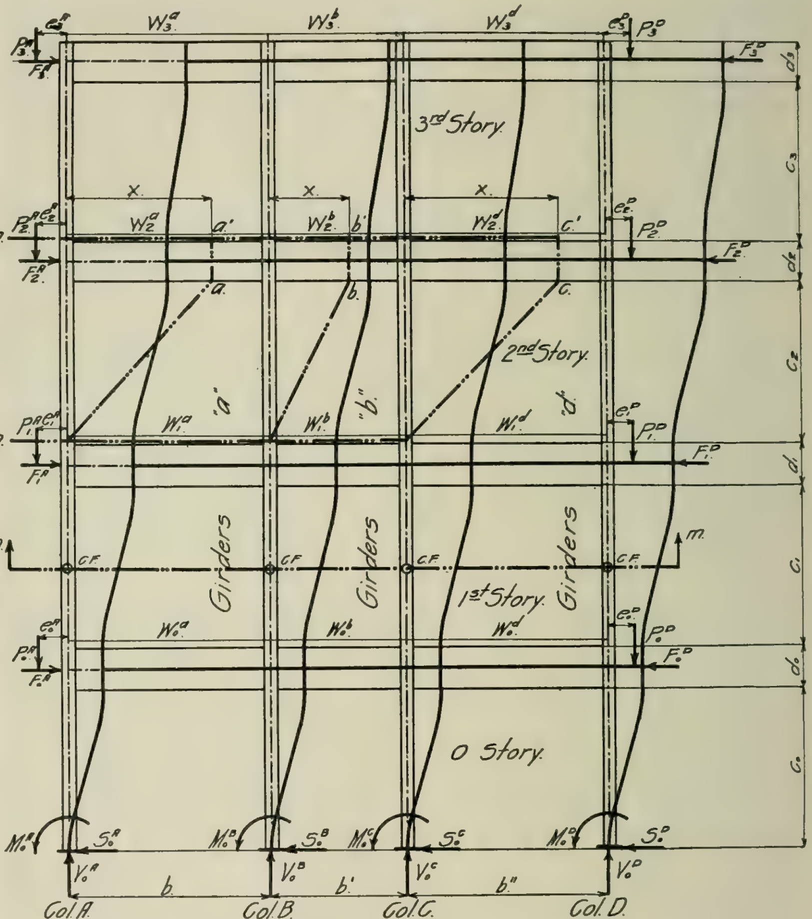


FIG 3a.

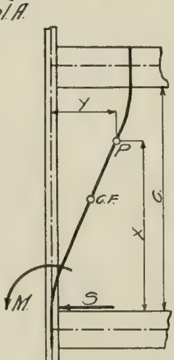


FIG 3b

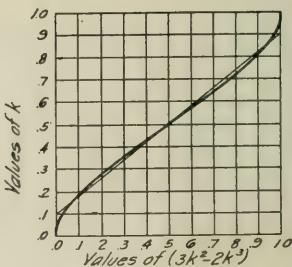


FIG 3c

Also $y = 0$ when $x = 0$, hence $K' = 0$ and therefore

$$Ey = \frac{M}{2I}x^2 - \frac{S}{6I}x^3.$$

But $dy/dx = 0$ when $x = c$, hence $M = S\,(c/2)$ and therefore CF, *the point of contra-flexure, always occurs at mid height regardless of type or amount of loading.*

Substituting the value of M, just found, in the equation of the elastic line the equation becomes

$$Ey = \frac{S}{12I}(3cx^2 - 2x^3)$$

or, letting $x = kc$ where k is a decimal fraction,

$$Ey = \frac{Sc^3}{12I}(3k^2 - 2k^3).$$

By assigning to k values varying from 0 to 1, the shape of the elastic line is determined and this curve is shown in Fig. 3*c*. The shape of the curve is the same for all column sections in the building, the *amount* of the deflection being proportional to Sc^3/I. The light straight line shown in Fig. 3*c* suggests a quick approximate method for constructing these curves, the major part of the curve being nearly straight.

When

$$x = c, \quad Ey = \delta = \frac{Sc^3}{12I};$$

but, since the girders are rigid

$$\delta^A = \delta^B = \delta^C = \delta^D$$

(Fig. 3, *a*). Hence

$$\frac{S^A c^3}{12I^A} = \frac{S^B c^3}{12I^B} = \frac{S^C c^3}{12I^C} = \frac{S^D c^3}{12I^D}$$

or

$$\frac{S^A}{I^A} = \frac{S^B}{I^B} = \frac{S^C}{I^C} = \frac{S^D}{I^D}$$

or

$$S^B = S^A\frac{I^B}{I^A};\ S^C = S^A\frac{I^C}{I^A};\ S^D = S^A\frac{I^D}{I^A}.$$

Now $S^A + S^B + S^C + S^D = \Sigma F$, the total wind shear on a section of the building cutting columns A, B, C, and D. Therefore, substituting the above values of S^B, S^C, and S^D and solving,

$$S^A = \frac{I^A}{I^A + I^B + I^C + I^D} \Sigma F$$

and therefore

$$S^B = \frac{I^B}{I^A + I^B + I^C + I^D} \Sigma F; \; S^C = \frac{I^C}{I^A + I^B + I^C + I^D} \Sigma F$$

and

$$S^D = \frac{I^D}{I^A + I^B + I^C + I^D} \Sigma F.$$

It must now be clear that the bending moment in a column, by this theory is entirely independent of both floor and eccentric column loads, depending entirely on lateral or wind forces, and that this moment is maximum and equal at the two extremities of each column section and at these points amounts to $S(c/2)$. Also, since ΣF and $I^A + I^B + I^C + I^D$ are constant for any given story the shears and maximum moments in the several columns are directly proportional to the moments of inertia of the several respective columns.

AXIAL STRESSES IN COLUMNS.

It has often been suggested that a building under the action of wind pressure acts like a solid beam. Referring to Fig. 4, *a*, let NA be the neutral axis of the structure shown, in accordance with the beam theory and let s be the unit axial compressive stress at units distance to the right of NA—due to flexure alone.

Now, passing a horizontal section "*mm*" through the points of contra-flexure of the columns, suppose there exists at P (Fig. 4*a*) a clockwise external bending moment X due to forces of any nature acting on the upper part of the structure cut by "*mm*." If any or all of the load producing this bending moment X is vertical, the resultant unit axial stresses in the columns will be represented by Fig. 4, *b*, as the quantities AA', BB', CC', DD', and EE'. The unit stresses shown in heavy lines and marked s^A, s^B, s^C, s^D, and s^E are the stresses due to the bending moment X alone, while the unit stresses $AA'' = BB'' = CC'' = DD'' = EE''$ are due to the effect

the vertical load would have if concentrated at the neutral axis. If Y represents the amount of this vertical load and the unit stress AA'' be represented by P, then

$$P(A^A + A^B + A^C + A^D + A^E) = Y$$

or

$$P = \frac{Y}{A^A + A^B + A^C + A^D + A^E}.$$

It must be evident from this equation that the "beam assumption" will not hold for vertical loads, for

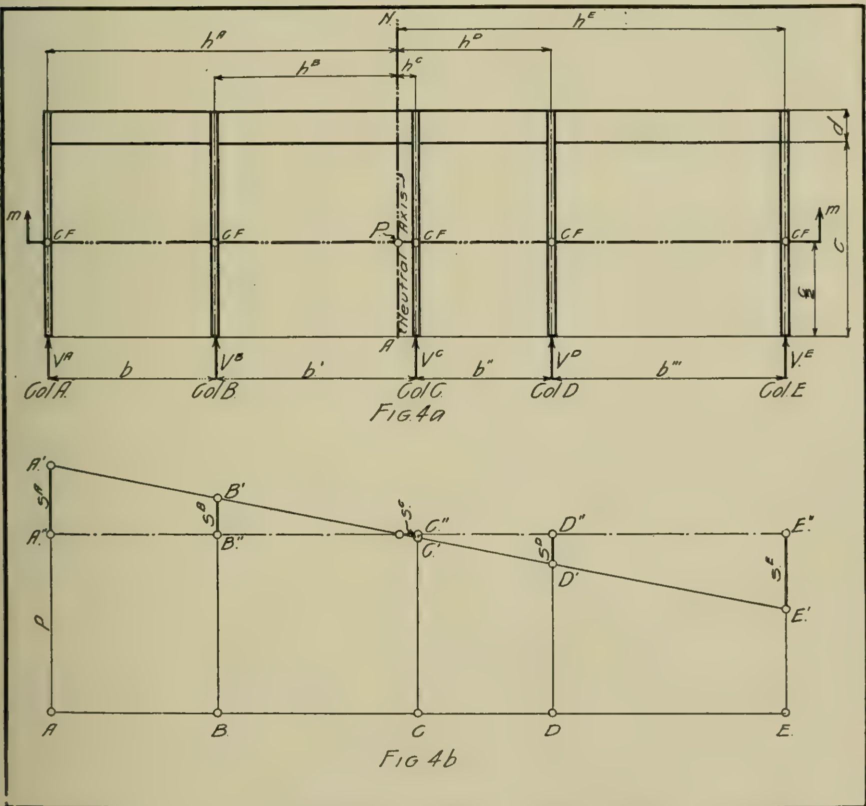


FIG. 4a

FIG. 4b

Suppose a heavy concentrated load placed vertically over P (Fig. 4, a), Columns A, B, C, D, and E would, by this theory, settle

equal amounts under the load and receive the same unit stress. Considering the *very small size* of this settlement an engineer would not be justified in estimating any of this load to be carried through the girders to columns A, D, or E, but should estimate it all as going to columns B and C. However, since buildings are usually designed for constant uniform loads covering the entire floor and since the areas A, of the columns, are estimated roughly on the basis of a constant value of ρ for any floor, the above method would not differ widely, as a rule, from more practical methods. It is not the purpose of this chapter to give the suggestions and methods resulting from this investigation (see Chapter XVI), but rather to develop and apply a consistent theory based on rigidity of floor girders.

Referring now to the unit stresses due to the bending moment X alone, these stresses may be written

$$s^A = -h^A s;\ s^B = -h^B s;\ s^C = h^C s;\ s^D = h^D s;\ s^E = h^E s,$$

since the unit stress from flexure on a beam is zero at the neutral axis and varies directly as the distance from the neutral axis. The sum of all of the total column stresses due to X must equal zero. Hence

$$s^A A^A + s^B A^B + s^C A^C + s^D A^D + s^E A^E = 0$$

or, substituting the above values of s^A, s^B, s^C, s^D and s^E and remembering that

$$h^A = b + b' - h^C;\ h^B = b' - h^C;\ h^D = b'' + h^C$$

and

$$h^E = b'' + b''' + h^C$$

there results

$$s[-A^A(b + b') - A^B b' + h^C(A^A + A^B + A^C + A^D + A^E) + A^D b'' + A^E(b'' + b''')] = 0$$

or

$$h^C = \frac{A^A(b + b') + A^B b' - A^D b'' - A^E(b'' + b''')}{A^A + A^B + A^C + A^D + A^E}.$$

Thus, after estimating the column areas the position of the neutral axis is readily determined; then h^A, h^B, h^D, and h^E, are evaluated

as above. Now in order to balance the bending moment X the following relation must exist, viz.,—

$$V^A h^A - V^B h^B + V^C h^C + V^D h^D + V^E h^E = X$$

where

$$V^A = s^A A^A;\quad V^B = s^B A^B;\quad V^C = s^C A^C;\quad V^D = s^D A^D;\quad V^E = s^E A^E.$$

Making the substitution there results

$$s[A^A h^{A^2} + A^B h^{B^2} + A^C h^{C^2} + A^D h^{D^2} + A^E h^{E^2}] = X,$$

from which s is readily found. Now s^A, s^B, s^C, s^D, and s^E may be found from relations previously given and then the column stresses due to X, viz., V^A, V^B, V^C, V^D, and V^E. A short summary of the method of designing columns is now given as follows:

First, assume the depths of girder and story heights; all the columns can then be designed independently of the girders.

Second, estimate roughly the width of column web plate such that the minimum top sections will not be too wasteful of material and the bottom sections will not be uneconomical due to a too small radius of gyration.

Third, start at the top of the building so that column and fire-procfing weights may be added as the design progresses. Compute and tabulate values of X and Y for each floor.

Fourth, estimate by trial the sections for the top floor, computing the position of the neutral axis and the axial and flexural unit column stresses, rough approximations being taken as a start and the design revised until satisfactory. Then proceed to the next floor below.

It is well to note here that there are two methods in use in arranging column sections. They differ only in the location of column splices. In the early history of tall buildings column splices were considered points of weakness and there originated the method of "staggered splices," *i. e.*, only every alternate column spliced at a floor. In later practice column splices and confidence in them improved; when properly made they may be considered stronger than the main section of the column. On this basis the columns may as well be all spliced at the same floor, thus

facilitating erection. Especially is this method valuable in a reinforced concrete building, allowing all columns and floor slabs for the same floor to be poured at one time. It should be remembered that columns are usually designed in two story lengths for economy in shipping, erection, and number of splices, two stories usually making about a car length (30 feet). When splices are "staggered" the method of approximating and recalculating is a little more difficult. The example given later illustrates this case.

STRESSES AND DESIGN OF FLOOR GIRDERS.

Referring to Fig. 3, *a*, stresses are obtained as follows:

Girder A_2—Top Flange.—Pass a section *naa'n* as shown; then, taking moments around point "a" the top flange compressive stress equals

$$\frac{1}{d_2}\left\{S_2^A c_2 + S_3^A d_2 + (V_2^A - V_3^A)x + F_2^A\frac{d_2}{2} - P_2^A(e_2^A + x) - \frac{w_2x^2}{2} - M_2^A + M_3^A\right\}$$

$$= S_2^A\frac{c_2}{2d_2} + S_3^A\frac{(c_3+2d_2)}{2d_2} + \frac{F_2^A}{2} - P_2^A\frac{(e_2^A+x)}{d_2} + (V_2^A - V_3^A)\frac{x}{d_2} - \frac{w_2x^2}{2d_2}.$$

The maximum compression in the top flange is usually given by this expression when $x = 0$ and the maximum tension when $x = b$, changing the signs throughout.

Girder A_2—Bottom Flange.—Using the same section as above and taking moments around point a' the bottom flange tensile stress equals

$$S_2^A\frac{(c_2+2d_2)}{2d_2} + S_3^A\frac{c_3}{2d_2} - \frac{1}{2}F_2^A - P_2^A\frac{(e_2^A + x)}{d_2} + (V_2^A - V_3^A)\frac{x}{d_2} - \frac{w_2x^2}{2d_2}.$$

The maximum tension in the bottom flange is given when $x = 0$ and the maximum compression when $x = b$, changing signs throughout.

Girder b_2—Top Flange.—Pass a section *nbb'n* as shown and take moments about b. The top flange compressive stress equals

$$(S_2^A + S_2^B)\frac{c_2}{2d_2} + (S_3^A + S_3^B)\frac{(c_3 + 2d_2)}{2d_2} + \tfrac{1}{2}F_2^A - P_2^A\frac{(e_2^A + b + x)}{d_2}$$

$$+ (V_2^A - V_3^A)\frac{b}{d_2} + (V_2^A - V_3^A + V_2^B - V_3^B)\frac{x}{d_2} - \frac{w_2b^2}{2d_2} - \frac{w_2\left(bx + \frac{x^2}{2}\right)}{d_2},$$

the maximum compression occurring for $x = 0$ and maximum tension for $x = b'$, changing all signs.

Girder b_2—Bottom Flange.—Using the same section as above and taking moments around point b' the bottom flange tensile stress equals

$$(S_2^A + S_2^A)\frac{(c_2+2d_2)}{2d_2} + (S_3^A + S_3^B)\frac{c_3}{2d_2} - \tfrac{1}{2}F_2^A - P_2^A\frac{(e_2^A + b + x)}{d_2}$$

$$+(V_2^A - V_3^A)\frac{b}{d_2} + (V_2^A - V_3^A + V_2^B - V_3^B)\frac{x}{d_2} - \frac{w_2 b^2}{2d_2} - \frac{w_2\left((bx + \frac{x^2}{2}\right)}{d_2},$$

the maximum tension occurring for $x = 0$ and maximum compression for $x = b'$, changing all signs.

Girder c_2—Top Flange.—Pass a section $ncc'n$ as shown and take moments about c. The top flange compressive stress equals

$$(S_2^A + S_2^B + S_2^C)\frac{c_2}{2d_2} + (S_3^A + S_3^B + S_3^C)\frac{(c_3+2d_2)}{2d_2}$$

$$+\tfrac{1}{2}F_2^A - P_2^A\frac{(e_2^A + b + b' + x)}{d_2} + (V_2^A - V_3^A)\frac{b}{d_2}$$

$$+(V_2^A - V_3^A + V_2^B - V_3^B)\frac{b'}{d_2} + (V_2^A - V_3^A + V_2^B - V_3^B + V_2^C - V_3^C)\frac{x}{d_2}$$

$$-\frac{w_2(b+b')^2}{2d_2} - \frac{w_2\left[(b+b')x + \frac{x^2}{2}\right]}{d_2},$$

the maximum compression occurring for $x = 0$ and maximum tension for $x = b''$, changing all signs.

Girder c_2—Bottom Flange.—Using the same section as above and taking moments around point c' the bottom flange tensile stress equals

$$(S_2^A + S_2^B + S_2^C)\frac{(c_2+2d_2)}{2d_2} + (S_3^A + S_3^B + S_3^C)\frac{c_3}{2d_2}$$

$$-\tfrac{1}{2}F_2^A - P_2^A\frac{(e_2^A + b + b' + x)}{d_2} + (V_2^A - V_3^A)\frac{b}{d_2}$$

$$+(V_2^A - V_3^A + V_2^B - V_3^B)\frac{b'}{d_2} + (V_2^A - V_3^A + V_2^B - V_3^B + V_2^C) - V_3^C)\frac{x}{d_2}$$

$$-\frac{w_2(b+b')^2}{2d_2} - \frac{w_2\left[(b+b')x + \frac{x^2}{2}\right]}{d_2},$$

the maximum tension occurring for $x = 0$ and maximum compression for $x = b''$, changing all signs.

The above girder equations have been written for the second story. For any other story equations may be written by merely changing the subscripts in these to correspond with the story under consideration. It must also be clear now how the equations change for changes in the number of panels constituting the width of the building.

THE DESIGN OF A PLAIN PLATE GIRDER PORTAL BRACED BUILDING — GIRDERS ASSUMED RIGID.

The method just given will now be applied to a five story structure with only two columns in a cross section. (See Fig. 5, *a*.) A structure of this simple type is taken as fully illustrating the method of design and as a basis for the investigation of stresses in future chapters on the assumption of a *perfectly elastic structure*. Fig. 5, *a*, shows the dimensions of the structure and the location of the staggered column splices. Fig. 5, *b*, shows the location of floor beams and area contributing load to the columns and girders. All floors are arranged alike and *every* transverse column section of the structure is considered as portal braced; it is believed that this is most economical and gives a more uniform design. Figs. 5*c* and 5*d* show the location and eccentricity of wall beams, the connection of these beams to the columns and the position of the front and rear walls relative to the columns. In this design the floor load is not considered as uniform but as concentrated at the beam connections.

Unit Loads—Live Load.—Roof, 30 ℔ per. sq. ft.; 1st, 2d, and 3d floors, 50 ℔ per sq. ft.; 0 floor, 100 ℔ per sq. ft.

Dead Load.—Roof and 1st, 2d, and 3d floors, 90℔ per sq. ft.; 0 floor, 110 ℔ per sq. ft.; walls, face, 94 ℔ per sq. ft. of surface (75 per cent of solid wall), rear, 125 ℔ per sq. ft. of surface (no windows); parapet on face, extending 5 feet above centre of roof girder @ 125 ℔ per sq. ft. of surface; column fireproofing, 100 ℔ per lineal foot of column.

Wind Load.—30 ℔ per sq. ft. of exposed surface. Consider that the wind may act on face or rear and that the exposed surface of face and rear are equal, *i. e.*, as if the rear wall also had a parapet.

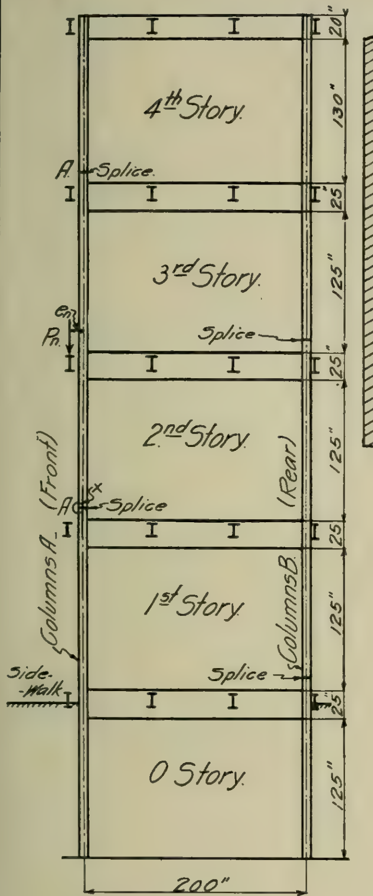


FIG 5a.

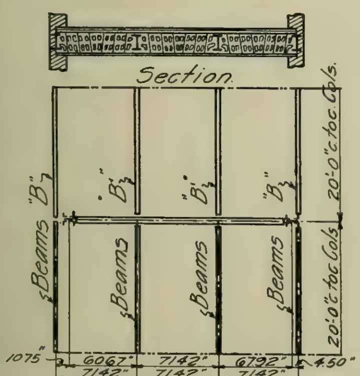


FIG 5b.

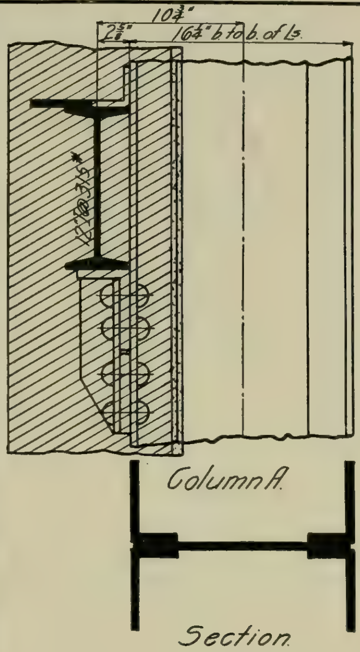


FIG 5c.

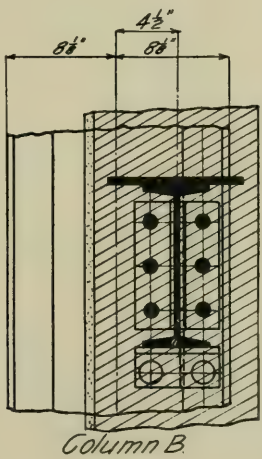


FIG 5d.

It will be noted that no reduction of live load on floors is provided for in the column designs. It is desired to keep girder and column loading identical for the purposes of this discussion.

Allowed Unit Stresses.—

Tension, 16,000 lb per sq. in., net.	
Compression, 16,000–70 L/r per sq. in. gross.	L = unsupported length;
Bending-tension fibre, 16,000 lb per sq. in., net.	r = least radius of gyration;
Bending-comp. fibre, 16,000–200 L/b per sq. in., gross.	b = width of girder flange;
Shear on webs of girders, 10,000 lb per sq. in., gross.	L, r, and b in inches.

An increase in the above units of 25 per cent. will be allowed when wind stresses are included, but, if this requires less material than is required for the other stresses, exclusive of wind, at the above units, the wind stresses shall be disregarded.

A rough trial shows that 16 in. may be used for the width of the column web plates Figs. 5, *c*, and 5, *d*, show that the concentrated loads P^A will have an eccentricity of 10.75 in. while the loads P^B will have an eccentricity of 4.50 in. In order that all floor arch spans may be the same the spacing of floor beams is made constant as shown in Fig. 5, *b*.

Values of P^A Due to Wall Load Only.—

P_4^A = 20.0 ft. × 5.0 ft. × 125 lb = 12,500 lb.

$P_3^A = P_2^A = P_1^A = P_0^A$ = 20.0 ft. × 12.5 ft. × 94 lb = 23,500 lb.

Values of P^B Due to Wall Load Only.—

$P_4^B = 0$.

$P_3^B = P_2^B = P_1^B = P_0^B$ = 20.0 ft. × 12.5 ft. × 125 lb = 31,225 lb.

Values of $F^A = F^B$.—

F_4^A = 20.0 ft. (5.0 ft. + 6.25 ft.) × 30 lb = 6,750 lb.

$F_3^A = F_2^A = F_1^A$ = 20.0 ft. × 12.5 ft. × 30 lb = 7,500 lb.

$F_0^A = \frac{1}{2}F_3^A$ = 3,750 lb.

Floor Beam Concentration.—Let W be the concentration from

floor beams B, and W', that from beams B'. Then

$$W_4 = \frac{71.42 \text{ in.}}{24} \times 20.0 \text{ ft.} \times (30 \text{ lb} + 90 \text{ lb}) = 7{,}142 \text{ lb};$$
$$W_4' = 2W_4 = 14{,}284 \text{ lb}.$$
$$W_3 = W_2 = W_1 = \frac{71.42 \text{ in.}}{24} \times 20.0 \text{ ft.} \times (50 \text{ lb} + 90 \text{ lb}) = 8{,}325 \text{ lb};$$
$$W_3' = 2W_3 = W_2' = W_1' = 16{,}650 \text{ lb}.$$
$$W_0 = \frac{71.42 \text{ in.}}{24} \times 20.0 \text{ ft.} \times (100 \text{ lb} + 110 \text{ lb}) = 12{,}500 \text{ lb};$$
$$W_0' = 2W_0 = 25{,}000 \text{ lb}.$$

The general formulae for determining column stresses reduce in this case 25 to the following.

$$h^B = \frac{bA^A}{A^A + A^B} = 200 \times \frac{A^A}{A^A + A^B}, \quad h^A = 200 - h^B, \quad p = \frac{Y}{A^A + A^B}.$$
$$X = h^B Y + \Sigma P^B e^B - \Sigma p^A(b + e^A) - 205.26 \Sigma W' + X_w,$$

where X_w is the value of X for wind only; this will be plus if the wind blows on the front and minus if the wind blows on the rear of the building.

$$s = \frac{X}{A^A h^{A^2} + A^B h^{B^2}}, \quad s^A = -h^A s, \quad s^B = h^B s,$$

$$s'^A = \frac{I^A}{I^A + I^B} \times \frac{\Sigma F \frac{C}{2}}{\frac{I^A}{V^A}}, \quad s'^B = \frac{I^B}{I^A + I^B} \times \frac{\Sigma F \frac{C}{2}}{\frac{I^B}{V^B}}.$$

The maximum compressive unit stress in column $A = p + s^A + s'^A$ and occurs for wind blowing on rear.

The maximum compressive unit stress in column $B = p + s^B + s'^B$ and occurs for wind blowing on front.

Data for column design is given in the following table.

Floor.	Total P^A, lbs.	ΣP^A, lbs.	Total P^B, lbs.	ΣP^B, lbs.	W', lbs.	$\Sigma W'$, lbs.	*Y, lbs.	$F^A = F^B$.	ΣF, lbs.
4	19,642	19,642	7,142	7,142	14,284	14,284	55,352	6,750	6,750
3	31,825	51,467	39,550	46,692	16,650	30,934	160,027	7,500	14,250
2	31,825	83,292	39,550	86,242	16,650	47,584	264,702	7,500	21,750
1	31,825	115,117	39,550	125,792	16,650	64,234	369,377	7,500	29,250
0	36,000	151,117	43,725	169,517	25,000	89,234	499,102	3,750	33,000

* These values are exclusive of column weights and column fireproofing, for which values will be added as the columns are designed. The various trials made in securing the following sections will not be given; in any given case these trials will be governed by the experience of the designer.

Fourth Story—Columns.—

For Column 4–A use

$$\left.\begin{array}{l} 4\angle\text{'s, } 3 \times 2\tfrac{1}{2} \times \tfrac{5}{16} \\ \\ \\ 1 \text{ Pl., } 16 \times \tfrac{5}{16} \end{array}\right\} \begin{array}{lcl} A & = & 11.52 \text{ sq. in.} \\ I & = & 461.0 \\ r & = & 1.15 \text{ in.} \\ \dfrac{I}{v} & = & 57.7 \\ w_c & = & 39.0 \text{ lb} \end{array}$$

Y_4 (from table) =		55,350 lb
Wgt. Col. 4–A	= 12.5 ft. × 39.0 lb =	490 lb
Wgt. Col. 4–B	= 12.5 ft. × 51.8 lb =	650 lb
F.P. Col. 4–A	= 12.5 ft. × 100 lb =	1,250 lb
F.P. Col. 4–B	= 12.5 ft. × 100 lb =	1,250 lb
Total value of Y_4 =		58,990 lb

For Column 4–B use

$$\left.\begin{array}{l} 4\angle\text{'s, } 5 \times 3\tfrac{1}{2} \times \tfrac{5}{16} \\ \\ \\ 1 \text{ Pl., } 16 \times \tfrac{5}{16} \end{array}\right\} \begin{array}{lcl} A & = & 15.23 \text{ sq. in.} \\ I & = & 660.8 \\ r & = & 1.94 \text{ in.} \\ \dfrac{I}{v} & = & 81.3 \\ w_c & = & 51.8 \text{ lb} \end{array}$$

$$\Sigma F \frac{c}{2} = 6{,}750 \times 65.0 = 438{,}000 \text{ in. lb}$$

$$h^B = 200 \frac{11.52}{11.52 + 15.23} = 86.1 \text{ in.,} \quad h^A = 200 - 86.1 = 113.9 \text{ in.,}$$

$$p = \frac{58{,}990}{11.52} + 15.23 = 2{,}205 \text{ lb per sq. in.}$$

$h^B Y$.	$\Sigma P^B e^B$.	$-\Sigma P^A(b+e^A)$.	$-205.26\Sigma W$.	X_w.	Wind on Front. X.	Wind on Rear. X.
+5,090,000	+32,200	−4,145,000	−2,930,000	±506,500	−1,446,300	−2,459,300

$$s \text{ (wind on rear)} = -\frac{2{,}459{,}300}{11.52 \times 113.9^2 + 15.23 \times 86.1^2}$$

$$= -9.38 \text{ lb per sq. in.}$$

s^A, max. comp., wind on rear $= 113.9 \times 9.38 = +1{,}067$ lb per sq. in.

$$s'^A \text{ max. comp} = \frac{461.0}{461.0 + 660.8} \times \frac{438{,}000}{57.7} = +3{,}125 \text{ lb per sq. in.}$$

$$\begin{aligned} \text{Max. unit. comp. stress in Col. } 4\text{–}A,\ p &= +2{,}205 \text{ lb per sq. in.} \\ s^A &= +1{,}067 \text{ lb per sq. in.} \\ s'^A &= +\underline{3{,}125} \text{ lb per sq. in.} \\ \text{Total} &= +6{,}397 \text{ lb per sq. in.} \end{aligned}$$

Max. allowed unit comp. stress in Col. 4–A

$$= 1.25\left(16{,}000 - 70 \times \frac{150}{1.94}\right) = +8{,}380 \text{ lb per sq. in.}$$

This column section will be O.K.

$$s \text{ (wind on front)} = -\frac{1{,}446{,}300}{11.52 \times 113.9^2 + 15.23 \times 86.1^2} = -5.51.$$

s^B, max. comp. wind on face $= -86.1 \times 5.51 = -475$ lb per sq. in.

$$s'^B, \text{ max. comp.} = \frac{660.8}{461.0 + 660.8} \times \frac{438{,}000}{81.3} = +3{,}175 \text{ lb per sq. in.}$$

$$\begin{aligned} \text{Max. unit comp. stress in Col. } 4\text{–}B,\ p &= +2{,}205 \text{ lb per sq. in.} \\ s^B &= -475 \text{ lb per sq. in.} \\ s'^B &= +\underline{3{,}175} \text{ lb per sq. in.} \\ \text{Total} &= +4{,}905 \text{ lb per sq. in.} \end{aligned}$$

Splice occurs in Col. 3–B, hence see third story for allowed and max. stresses.

Third Story—Columns.—

For Column 3–A use

$$\left.\begin{array}{l} 4\angle\text{'s, } 6 \times 3\tfrac{1}{2} \times \tfrac{3}{8} \\ \\ \\ 1 \text{ Pl., } 16 \times \tfrac{3}{8} \end{array}\right\} \begin{array}{ll} A &= 19.73 \text{ sq. in.} \\ I &= 878.6 \\ r &= 2.46 \text{ in.} \\ \dfrac{I}{v} &= 108.1 \\ w_c &= 67.2 \text{ lb} \end{array}$$

Y_3 (from table)			=	160,027 lb
Col. wgts. and F.P. from above			=	3,640 lb
Wgt. col. 3–A	= 12.5 ft. ×	67.2 lb	=	840 lb
Wgt. col. 3–B	= 12.5 ft. ×	51.8 lb	=	650 lb
F.P. col. 3–A	= 12.5 ft. ×	100 lb	=	1,250 lb
F.P. col. 3–B	= 12.5 ft. ×	100 lb	=	1,250 lb
Total value of Y_3 =				167,657 lb

For Column 3–B use

$$\left.\begin{array}{l} 4\angle\text{'s, } 5 \times 3\tfrac{1}{2} \times \tfrac{5}{16} \\ \\ 1 \text{ Pl., } 16 \times \tfrac{5}{16} \end{array}\right\} \begin{array}{l} A = 15.23 \text{ sq. in.} \\ I = 660.8 \\ r = 1.94 \text{ in.} \\ \dfrac{I}{v} = 81.3 \\ w_c = 51.8 \text{ lb} \end{array}$$

$$\Sigma F\frac{c}{2} = 14{,}250 \times 62.5 = 891{,}500 \text{ in. lb}$$

$$h^B = 200 \times \frac{19.73}{19.73 + 15.23} = 112.8 \text{ in.}$$

$$h^A = 200.0 - 112.8 = 87.2 \text{ in.}$$

$$p = \frac{167{,}657}{19.73 + 15.23} = 4{,}785 \text{ lb per sq. in.}$$

$h^B Y$.	$\Sigma P^B c^B$.	$-\Sigma P^A(b+c^A)$.	$-205.26 \Sigma W'$.	X_w.	Wind on Front. X.	Wind on Rear. X.
+18,940,000	+210,000	−10,840,000	−6,345,000	±2,096,000	+4,061,000	−131,000

$$s \text{ (wind on rear)} = -\frac{131{,}000}{19.73 \times 87.2^2 + 15.23 \times 112.8^2}$$

$$= -0.381 \text{ lb per sq. in.}$$

s^A, max. comp., wind on rear = 87.2×0.381 = + 33 lb per sq. in

$$s'^A\text{, max. comp.} = \frac{878.6}{878.6 + 660.8} \times \frac{891{,}500}{108.1} = +4{,}720 \text{ lb per sq. in.}$$

Max. unit. comp. stress in Col. 3–A,	p	=	+ 4,785 lb per sq. in.
	s^A	=	+ 33 lb per sq. in.
	s'^A	=	+ 4,720 lb per sq. in.
	Total	=	+ 9,538 lb per sq. in.

Splice occurs in Col. 2–A; hence see second story for allowed and max. stresses.

$$s \text{ (wind on front)} = + \frac{4{,}061{,}000}{19.73 \times 87.2^2 + 15.23 \times 112.8^2}$$

$$= + 11.80 \text{ lb per sq. in.}$$

s^B, max. comp., wind on front, $= 112.8 \times 11.80$

$$= + 1{,}332 \text{ lb per sq. in.}$$

$$s'^B, \text{ max. comp.} = \frac{660.8}{878.6 + 660.8} \times \frac{891{,}500}{81.3} = + 4{,}710 \text{ lb per sq. in.}$$

Max. unit. comp. stress in Col. 3–B, p	= + 4,785	lb per sq. in.
s^B	= + 1,332	lb per sq. in.
s'^B	= + 4,710	lb per sq. in.
Total	= + 10,827	lb per sq. in.

Max. allowed unit comp. stress in Col. 3–B

$$= 1.25\left(16{,}000-70 \times \frac{150}{1.94}\right) = + 13{,}250 \text{ lb per sq. in.}$$

If the next smaller section ($4 \times 3 \times \frac{5}{16}$ in. ∠'s) were used the allowed stress would be only 11,500 lb per sq. in. and the max. stress would be 12,240 lb per sq. in. instead of the 10,827 lb per sq. in. above. The section used is O.K.

Second Story—Columns.—

For Column 2–A use

$$\left.\begin{array}{l} 4\angle\text{'s, } 6 \times 3\tfrac{1}{2} \times \tfrac{3}{8} \\ \\ 1 \text{ Pl., } 16 \times \tfrac{3}{8} \end{array}\right\} \begin{array}{l} A = 19.73 \text{ sq. in.} \\ I = 878.6 \\ r = 2.46 \text{ in.} \\ \frac{I}{v} = 108.1 \\ w_c = 67.2 \text{ lb} \end{array}$$

Y_2 (from table)		=	264,702 lb
Col. wgts. and F.P. from above		=	7,630 lb
Wgt. Col. 2–A	= 12.5 ft. × 67.2 lb	=	840 lb
Wgt. Col. 2–B	= 12.5 ft. × 83.8 lb	=	1,050 lb

F.P. Col. 2–A = 12.5 ft. × 100 lb = 1,250 lb
F.P. Col. 2–B = 12.5 ft. × 100 lb = 1,250 lb
Total value of Y_2 = 276,720 lb

For Column 2–B use

$$\left.\begin{array}{l} 4\angle\text{'s, } 7 \times 3\tfrac{1}{2} \times \tfrac{7}{16} \\ \\ \\ 1 \text{ Pl., } 16 \times \tfrac{7}{16} \end{array}\right\} \begin{array}{lcl} A & = & 24.65 \text{ sq. in.} \\ I & = & 1,122.6 \\ r & = & 3.00 \text{ in.} \\ \dfrac{I}{V} & = & 138.2 \\ W_c & = & 83.8 \text{ lb} \end{array}$$

$$\Sigma F \frac{c}{2} = 21,750 \times 62.5 = 1,360.000 \text{ in. lb},$$

$$h^B = 200 \times \frac{19.73}{19.73 + 24.65} = 89.0 \text{ in.},$$

$$h^A = 200.0 - 89.0 = 111.0 \text{ in.},$$

$$p = \frac{276.720}{19.73 + 24.65} = 6,230 \text{ lb per sq. in.}$$

$h^B Y$.	$\Sigma P^B e^B$.	$-\Sigma P^A(b+e^A)$.	$-205.26 \Sigma W'$.	X_w.	Wind on Front. X.	Wind on Rear. X.
+24,620,000	+389,000	−17,550,000	−9,768,000	±4,798,000	+2,489,000	−7,107,000

$$s \text{ (wind on rear)} = -\frac{7,107,000}{19.73 \times 111.0^2 + 24.65 \times 89.0^2}$$

$$= -16.23 \text{ lb per sq. in.}$$

s^A, max. comp., wind on rear, $= 111.0 \times 16.23$

$$= +1,802 \text{ lb per sq. in.}$$

$$s'^A, \text{ max. comp.} = \frac{878.6}{878.6 + 1,122.6} \times \frac{1,360,000}{108.1}$$

$$= +5,525 \text{ lb per sq. in.}$$

Max. unit. comp. stress in Col. 2–A, p = + 6,230 lb per sq. in.
s^A = + 1,802 lb per sq. in.
s'^A = + 5,525 lb per sq. in.
Total = + 13,557 lb per sq. in.

Max. allowed unit comp. stress in Col. 2–A

$$= 1.25\left(16{,}000 - 70 \times \frac{150}{2.46}\right) = +\ 14{,}700 \text{ lb per sq. in.}$$

The section used can not be reduced.

$$s \text{ (wind on front)} = +\frac{2{,}489{,}000}{19.73 \times 111.0^2 + 24.65 \times 89.0^2}$$

$$= +\ 5.68 \text{ lb per sq. in.}$$

s^B, max. comp.-wind on front $= 89.0 \times 5.68 = +\ 506$ lb per sq. in.

$$s'^B, \text{ max. comp.} = \frac{1{,}122.6}{878.6 + 1122.6} \times \frac{1{,}360{,}000}{138.2}$$

$$= +\ 5520 \text{ lb per sq. in.}$$

Max. unit comp. stress in Col. 2–B, p	$= +$	6,230 lb per sq. in.
s^B	$= +$	506 lb per sq. in.
s'^B	$= +$	5,520 lb per sq. in.
Total	$=$	+12,256 lb per sq. in.

Splice occurs in Col. 1–A; hence see first story for allowed and max. stresses.

First Story—Columns.—

For Column 1–A use

$$\left.\begin{array}{l} 4\angle\text{'s, } 7 \times 3\tfrac{1}{2} \times \tfrac{5}{8} \\ \\ 1 \text{ Pl., } 16 \times \tfrac{5}{8} \end{array}\right\} \begin{array}{lcl} A & = & 34.73 \text{ sq. in.} \\ I & = & 1{,}550.9 \\ r & = & 3.08 \text{ in.} \\ \frac{I}{v} & = & 190.9 \\ w_c & = & 118.0 \text{ lb} \end{array}$$

Y_1 (from table) =		369,377 lb
Col. wgts. and F.P. from above	=	12,020 lb
Wgt. Col. 1–A = 12.5 ft. × 118.0 lb	=	1,480 lb
Wgt. Col. 1–B = 12.5 ft. × 83.8 lb	=	1,050 lb
F.P. Col. 1–A = 12.5 ft. × 100 lb	=	1,250 lb
F.P. Col. 1–B = 12.5 ft. × 100 lb	=	1,250 lb
Total value of Y_1	=	386,430 lb

For Column 1–B use

$$\left.\begin{array}{l} 4\angle\text{'s, } 7 \times 3\tfrac{1}{2} \times \tfrac{7}{16} \\ \\ 1\text{ Pl., } 16 \times \tfrac{7}{16} \end{array}\right\} \begin{array}{lcr} A & = & 24.65 \text{ sq. in.} \\ I & = & 1,122.6 \\ r & = & 3.00 \text{ in.} \\ \dfrac{I}{v} & = & 138.2 \\ w_c & = & 83.8 \text{ lb} \end{array}$$

$$\Sigma F \frac{c}{2} = 29,250 \times 62.5 = 1,827,000 \text{ in. lb}$$

$$h^B = 200 \times \frac{34.73}{34.73 + 24.65} = 117.0 \text{ in.}$$

$$h^A = 200.0 - 117.0 = 83.0 \text{ in.}$$

$$p = \frac{386,430}{34.73 + 24.65} = 6,510 \text{ lb per sq. in.}$$

$h^B V$.	$\Sigma P^B e^B$.	$-\Sigma P^A(b+e^A)$.	$-205.26\Sigma W'$.	X_w.	Wind on Front. X.	Wind on Rear. X.
+45,230,000	+565,000	−24,270,000	−13,175,000	±8,622,500	+16,972,500	−272,500

$$s \text{ (wind on rear)} = -\frac{272,500}{34.73 \times 83.0^2 + 24.65 \times 117.0^2}$$

$$= -0.472 \text{ lb per sq. in.}$$

s^A, max. comp., wind on rear $= 83.0 \times 0.472 = +39$ lb per sq. in.

$$s'^A, \text{ max. comp.} = \frac{1,550.9}{1550.9 + 1,122.6} \times \frac{1,827,000}{190.9}$$

$$= +5,550 \text{ lb per sq. in.}$$

$$\begin{array}{rcl} \text{Max. unit. comp. stress in Col. 1–}A,\ p & = & +\ \ 6,510 \text{ lb per sq. in.} \\ s^A & = & +\ \ \ \ \ \ 39 \text{ lb per sq. in.} \\ s'^A & = & +\ \ 5,550 \text{ lb per sq. in.} \\ \text{Total} & = & +12,099 \text{ lb per sq. in.} \end{array}$$

1–A and 0–A are the same member, hence see 0 story for allowed and max. stresses.

$$s \text{ (wind on front)} = +\frac{16,972,500}{34.73 \times 83.0^2 + 24.65 \times 117.0^2}$$

$$= +29.4 \text{ lb per sq. in.}$$

s^B, max. comp., wind on front = 117.0 × 29.4

= + 3,445 lb per sq, in.

$$s'^B\text{, max. comp.} = \frac{1{,}122.6}{1{,}550.9 + 1122.6} \times \frac{1{,}827{,}000}{138.2}$$

= + 5,550 lb per sq. in.

Max. unit. comp. stress in Col. 1–B, p	=	+ 6,510 lb per sq. in.
s^B	=	+ 3,445 lb per sq. in.
s'^B	=	+ 5,550 lb per sq. in.
Total	=	+15,505 lb per sq. in.

Max. allowed unit comp. stress in Col. 1–B

$$= 1.25\left(16{,}000 - 70 \times \frac{150}{3.00}\right) = +\ 15{,}620 \text{ lb per sq. in.}$$

The section used is O.K.

Basement Story—Columns.—

For Column 0–A use

4 ∠'s, 7 x $3\frac{1}{2}$ x $\frac{5}{8}$	A =	34.73 sq. in.
	I =	1,550.9
	r =	3.08 in.
1 Pl., 16 x $\frac{5}{8}$	$\frac{I}{v}$ =	190.9
	w_c =	118.0 lb

Y_0 (from table) =		499,102 lb
Col. wgts. and F.P. from above	=	17,050 lb
Wgt. Col. 0–A	= 12.5 ft. × 118.0 lb =	1,480 lb
Wgt. Col. 0–B	= 12.5 ft. × 118.0 lb =	1,480 lb
F.P. Col. 0–A	= 12.5 ft. × 100.0 lb =	1,250 lb
F.P. Col. 0–B	= 12.5 ft. × 100.0 lb =	1,250 lb
Total value of Y_0	=	521,610 lb

For Column 0–B use

$$\left.\begin{array}{l} 4\angle\text{'s, } 7 \times 3\tfrac{1}{2} \times \tfrac{5}{8} \\ \\ 1 \text{ Pl., } 16 \times \tfrac{5}{8} \end{array}\right\} \begin{array}{lcl} A & = & 34.73 \text{ sq. in.} \\ I & = & 1,550.9 \\ r & = & 3.08 \text{ in.} \\ \dfrac{I}{v} & = & 190.9 \\ w_c & = & 118.0 \text{ lb} \end{array}$$

$$\Sigma F \frac{c}{2} = 33,000 \times 62.5 = 2,062,500 \text{ in. lb}$$

$$h^B = 200 \times \frac{34.73}{34.73 + 34.73} = 100.0 \text{ in.}$$

$$h^A = 200.0 - 100.0 = 100.0 \text{ in.}$$

$$p = \frac{521,610}{34.73 + 34.73} = 7,510 \text{ lb per sq. in.}$$

$h^B V$.	$\Sigma P^B c^B$.	$-\Sigma P^A(b+c^A)$.	$-205.26 \Sigma W'$.	X_w.	Wind on Front. X.	Wind on Rear X.
+52,161,000	+763,000	−31,870,000	−18,300,000	±13,295,000	+16,049,000	−10,541,00

$$s \text{ (wind on rear)} = -\frac{10,541,000}{34.73 \times 100^2 + 34.73 \times 100^2}$$
$$= -15.175 \text{ lb per sq. in.}$$

s^A, max. comp., wind on rear $= 100 \times 15.17$
$$= +1,517 \text{ lb per sq. in.}$$

$$s'^A, \text{ max. comp.} = \frac{1,550.9}{1,550.9 + 1,550.9} \times \frac{2,062,500}{190.9}$$
$$= +5,405 \text{ lb per sq. in.}$$

Max. unit comp. stress in Col. 0–A, p $= +\ 7,510$ lb per sq. in.
s^A $= +\ 1,517$ lb per sq. in.
s'^A $= +\ 5,405$ lb per sq. in.
Total $= +14,432$ lb per sq. in.

Max. allowed unit comp. stress on Col. 0–A

$$= 1.25\left(16,000 - 70 \times \frac{150}{3.08}\right) = +16,150 \text{ lb per sq. in.}$$

If the next smaller section ($\frac{9}{16}$ in. material) were used the allowed stress would be 16,150 ℔ per sq. in. and the max. stress would be 16,340 ℔ per sq. in. instead of the 14,432 ℔ per sq. in. above. The section used is O.K.

$$s \text{ (wind on front)} = + \frac{16{,}049{,}000}{34.73 \times \overline{100}^2 + 34.73 \times \overline{100}^2}$$

$$= + 23.11 \text{ ℔ per sq. in.}$$

$$s^B, \text{ max. comp. wind on front} = 100 \times 23.11$$

$$= + 2{,}311 \text{ ℔ per sq. in.}$$

$$s'^B, \text{ max. comp.} = \frac{1{,}550.9}{1550.9 + 1550.9} \times \frac{2{,}062{,}500}{190.9}$$

$$= + 5{,}405 \text{ ℔ per sq. in.}$$

Max. unit. comp. stress in Col. o–B, p = +7,510 ℔ per sq. in.
s^B = + 2,311 ℔ per sq. in.
s'^B = + 5,405 ℔ per sq. in.
Total = +15,226 ℔ per sq. in.

Max. allowed unit comp. stress on Col. o–B

$$= 1.25 \left(16{,}000 - 70 \times \frac{150}{3.08}\right) = + 16{,}150 \text{ ℔ per sq. in.}$$

The section used is O.K.

Girder Design.—The general formulae for determining girder flange stresses reduce in this case to the following.

Girder A_n, top flange compression

$$= S_n^A \frac{c_n}{2d_n} + S_{n+1}^A \frac{c_{n+1}+2d_n}{2d_n} + \tfrac{1}{2}F_n^A + (V_n^A - V_{n+1}^A)\frac{x}{d_n} - P_n^A \frac{(e_n^A + x)}{d_n}$$

$$- W' \frac{(x - 60.67)}{d_n} \times 760.67 - \frac{W'(x - 132.09)}{d_n} \times 7132.09$$

Girder A_n, bottom flange tension

$$= S_n^A \frac{c_n + 2d_n}{2d_n} + S_{n+1}^A \frac{c_{n+1}}{2d_n} - \tfrac{1}{2}F_n^A + (V_n^A - V_{n+1}^A)\frac{x}{d_n} - P_n^A \frac{(e_n^A + x)}{d_n}$$

$$- W' \frac{(x - 60.67)}{d_n} \times 760.67 - \frac{W'(x - 132.09)}{d_n} \times 7132.09$$

The formulae apply for wind blowing on either front or rear when the corresponding values of S^A and V^A are used. For wind on the rear F^A is of course zero.

Values of V and S are given in the following paragraphs.

$$\left.\begin{aligned}
S_0^A &= \frac{1{,}550.9}{1{,}550.9 + 1{,}550.9} \times 33{,}000 = 16{,}500 \text{ lb} \\
S_1^A &= \frac{1{,}550.9}{1{,}550.9 + 1122.6} \times 29{,}250 = 16{,}970 \text{ lb} \\
S_2^A &= \frac{878.6}{878.6 + 1122.6} \times 21{,}750 = 9{,}553 \text{ lb} \\
S_3^A &= \frac{878.6}{878.6 + 660.8} \times 14{,}250 = 8{,}135 \text{ lb} \\
S_4^A &= \frac{461.0}{461.0 + 660.8} \times 6{,}750 = 2{,}773 \text{ lb} \\
S_0^B &= 33{,}000 - 16{,}500 = 16{,}500 \text{ lb} \\
S_1^B &= 29{,}250 - 16{,}970 = 12{,}280 \text{ lb} \\
S_2^B &= 21{,}750 - 9{,}553 = 12{,}197 \text{ lb} \\
S_3^B &= 14{,}250 - 8{,}135 = 6{,}115 \text{ lb} \\
S_4^B &= 6{,}750 - 2{,}773 = 3{,}977 \text{ lb}
\end{aligned}\right\}\ \begin{array}{l}+ \text{ for wind on} \\ \text{front; } - \text{ for} \\ \text{wind on rear.}\end{array}$$

The total axial stress in a column equals the area of the column times $(p + s)$.

The values of V are as follows: For wind on rear (Cols. A, max.).

$$\begin{aligned}
V_0^A &= 34.73 \times 9{,}027 = 313{,}500 \text{ lb} & V_0^A - V_1^A &= 86{,}100 \text{ lb} \\
V_1^A &= 34.73 \times 6{,}549 = 227{,}400 \text{ lb} & V_1^A - V_2^A &= 69{,}000 \text{ lb} \\
V_2^A &= 19.73 \times 8{,}032 = 158{,}400 \text{ lb} & V_2^A - V_3^A &= 63{,}270 \text{ lb} \\
V_3^A &= 19.73 \times 4{,}818 = 95{,}130 \text{ lb} & V_3^A - V_4^A &= 57{,}420 \text{ lb} \\
V_4^A &= 11.52 \times 3{,}272 = 37{,}710 \text{ lb} & V_4^A &= 37{,}710 \text{ lb}
\end{aligned}$$

$$\begin{aligned}
V_0^B &= Y_0 - V_0^A = 521{,}610 - 313{,}500 = 208{,}110 \text{ lb} \\
V_1^B &= Y_1 - V_1^A = 386{,}430 - 227{,}400 = 159{,}030 \text{ lb} \\
V_2^B &= Y_2 - V_2^A = 276{,}720 - 158{,}400 = 118{,}320 \text{ lb} \\
V_3^B &= Y_3 - V_3^A = 167{,}657 - 95{,}130 = 72{,}527 \text{ lb} \\
V_4^B &= Y_4 - V_4^A = 58{,}990 - 37{,}710 = 21{,}280 \text{ lb}
\end{aligned}$$

For Wind on Front (Cols. B, Max.).

$$V_0^B = 34.73 \times 9{,}821 = 341{,}000 \text{ lb}$$
$$V_1^B = 24.65 \times 9{,}955 = 245{,}400 \text{ lb}$$
$$V_2^B = 24.65 \times 6{,}736 = 166{,}000 \text{ lb}$$
$$V_3^B = 15.23 \times 6{,}117 = 93{,}230 \text{ lb}$$
$$V_4^B = 15.23 \times 1{,}730 = 26{,}360 \text{ lb}$$
$$V_0^A = Y_0 - V_0^B = 521{,}610 - 341{,}000 = 180{,}610 \text{ lb}$$
$$V_1^A = Y_1 - V_1^B = 386{,}430 - 245{,}400 = 141{,}030 \text{ lb}$$
$$V_2^A = Y_2 - V_2^B = 276{,}720 - 166{,}000 = 110{,}720 \text{ lb}$$
$$V_3^A = Y_3 - V_3^B = 167{,}657 - 93{,}230 = 74{,}427 \text{ lb}$$
$$V_4^A = Y_4 - V_4^B = 58{,}990 - 26{,}360 = 32{,}630 \text{ lb}$$
$$V_0^A - V_1^A = 39{,}580 \text{ lb}$$
$$V_1^A - V_2^A = 30{,}310 \text{ lb}$$
$$V_2^A - V_3^A = 36{,}293 \text{ lb}$$
$$V_3^A - V_4^A = 41{,}797 \text{ lb}$$
$$V_4^A = 32{,}630 \text{ lb}$$

The following table gives in a condensed form all the calculations of girder flange stresses and the positions and amounts of maximum stresses of both kinds in both top and bottom flanges.

Girder.	Flange.	Surface Facing Wind.	Value of x for Max. Stress.	S^A_n Term.	S^A_{n+1} Term.	$\frac{1}{2}F^A_n$.	$(V^A_n - V^A_{n+1})$ Term.	V^A_n Term.	Wy Terms.	Stresses, lbs.
a–4	Bottom	Front	200.00	−11,780	——	+3,380	−326,300	+207,000	+148,100	+ 20,400
		Front	60.67	+11,780	——	−3,380	+ 99,000	− 70,100	0	− 37,300
		Rear	0.00	+11,780	——	0	0	+ 10,600	0	+ 22,380
		Rear	132.09	−11,780	——	0	+249,100	−140,300	− 51,000	− 46,020
	Top	Front	60.67	+ 9,020	——	+3,380	+ 99,000	− 70,100	0	+ 41,300
		Front	200.00	− 9,020	——	−3,380	−326,300	+207,000	+148,100	− 16,400
		Rear	132.09	− 9,020	——	0	+249,100	−140,300	− 51,000	+ 48,780
		Rear	0.00	+ 9,020	——	0	0	+ 10,600	0	− 19,620
a–3	Bottom	Front	200.00	−28,480	− 7,215	+3,750	−334,376	+268,000	+138,100	+ 39,779
		Front	60.67	+28,480	+ 7,215	−3,750	+101,400	− 91,000	0	− 42,345
		Rear	0.00	+28,480	+ 7,215	0	0	+ 13,650	0	+ 49,345
		Rear	132.09	−28,480	− 7,215	0	+303,500	−182,000	− 47,500	− 38,305
	Top	Front	60.67	+20,330	+ 9,990	+3,750	+101,400	− 91,000	0	+ 44,470
		Front	200.00	−20,330	− 9,990	−3,750	−334,376	+268,000	+138,100	− 37,654
		Rear	132.09	−20,330	− 9,990	0	+303,500	−182,000	− 47,500	+ 43,680
		Rear	0.00	+20,330	+ 9,990	0	0	+ 13,650	0	− 43,970
a–2	Bottom	Front	200.00	−33,430	−20,330	+3,750	−290,344	+268,000	+138,100	+ 65,746
		Front	60.67	+33,430	+20,330	−3,750	+ 88,100	− 91,000	0	− 47,110
		Rear	0.00	+33,430	+20,330	0	0	+ 13,650	0	+ 67,410
		Rear	132.09	−33,430	−20,330	0	+334,500	−182,000	− 47,500	− 51,240
	Top	Front	60.67	+23,880	+28,480	+3,750	+ 88,100	− 91,000	0	+ 53,210
		Front	200.00	−23,880	−28,480	−3,750	−290,344	+268,000	+138,100	− 59,646
		Rear	132.09	−23,880	−28,480	0	+334,500	−182,000	− 47,500	+ 52,640
		Rear	0.00	+23,880	+28,480	0	0	+ 13,650	0	− 66,010

Girder.	Flange.	Surface Facing Wind.	Value of X for Max. Stress.	S^A_n Term.	S^A_{n+1} Term.	$\frac{1}{2}F^A_n$.	$(V^A_n - V^A_{n+1})$ Term.	P^A_n Term.	W' Terms.	Stresses, lbs.
a–1	Bottom	Front	200.00	−59,400	−23,880	+3,750	−242,480	+268,000	+138,100	+ 84,090
		Front	60.67	+59,400	+23,880	−3,750	+ 73,550	− 91,000	0	− 62,080
		Rear	0.00	+59,400	+23,880	0	0	+ 13,650	0	+ 96,930
		Rear	200.00	−59,400	−23,880	0	+552,000	−268,000	−138,100	− 62,620
	Top	Front	60.67	+42,430	+33,430	+3,750	+ 73,550	− 91,000	0	+ 62,160
		Front	200.00	−42,430	−33,430	−3,750	−242,480	+268,000	+138,100	− 84,010
		Rear	200.00	−42,430	−33,430	0	+552,000	−268,000	−138,100	+ 70,040
		Rear	0.00	+42,430	+33,430	0	0	+ 13,650	0	− 89,510
a–0	Bottom	Front	200.00	−57,770	−42,430	+1,875	−316,640	+303,500	+207,300	+ 95,835
		Front	60.67	+57,770	+42,430	−1,875	+ 96,050	−102,800	0	− 91,575
		Rear	0.00	+57,770	+42,430	0	0	+ 15,450	0	+115,650
		Rear	200.00	−57,770	−42,430	0	+688,800	−303,500	−207,300	− 77,800
	Top	Front	60.67	+41,260	+59,400	+1,875	+ 96,050	−102,800	0	+ 95,785
		Front	200.00	−41,260	−59,400	−1,875	−316,640	+303,500	+207,300	− 91,625
		Rear	200.00	−41,260	−59,400	0	+688,800	−303,500	−207,300	+ 77,340
		Rear	0.00	+41,260	+59,400	0	0	+ 15,450	0	−116,110

The design of the girders is given in the following table.

Girder.	Flange	Max. Stress. +	Max. Stress. −	Allowed Tens.	Allowed Comp. Unif.	Max. Area Required.	Make-up of Flanges.	Area Used.	Max. Shear.	Girder Web.
a–0	Top	95,785	116,110	1.25(16,000) = 20,000 net.	16,000	5.80 net.	2 $\angle$s, 6 x $3\frac{1}{2}$ x $\frac{3}{8}$*	5.55 net.	51,875	$26\frac{1}{2}$ x $\frac{3}{8}$
	Bottom	115,650	91,575		16,000	7.23 gr.	2 $\angle$s, 6 x $3\frac{1}{2}$ x $\frac{3}{8}$*	6.86 gr.		
a–1	Top	70,040	89,510		1.25(16,000 − 200 L/b) 15,200	4.48 net.	2 $\angle$s, 5 x $3\frac{1}{2}$ x $\frac{3}{8}$	4.79 net.	39,850	26 x $\frac{5}{16}$
	Bottom	96,930	62,620		15,200	6.38 gr.	2 $\angle$s, 5 x $3\frac{1}{2}$ x $\frac{3}{8}$*	6.10 gr.		
a–2	Top	53,210	66,010		15,200	3.30 net.	2 $\angle$s, 5 x 3 x $\frac{5}{16}$	3.73 net.	33,220	26 x $\frac{5}{16}$
	Bottom	67,410	51,240		15,200	4.43 gr.	2 $\angle$s, 5 x 3 x $\frac{5}{16}$	4.82 gr.		
a–3	Top	44,470	43,970		15,200	2.93 gr.	2 $\angle$s, 5 x 3 x $\frac{5}{16}$†	4.82 gr.	27,320	$26\frac{1}{2}$ x $\frac{5}{16}$
	Bottom	49,345	42,345		13,200	3.24 gr.	2 $\angle$s, $3\frac{1}{2}$ x 3 x $\frac{5}{16}$	3.88 gr.		
a–4	Top	48,780	19,620		13,200	3.21 gr.	2 $\angle$s, $3\frac{1}{2}$ x 3 x $\frac{5}{16}$	3.88 gr.	19,218	$21\frac{1}{2}$ x $\frac{5}{16}$
	Bottom	22,380	46,020		13,200	2.30 net.	2 $\angle$s, $3\frac{1}{2}$ x 3 x $\frac{5}{16}$	3.33 net.		

* Larger sections should have been used. N. B.—Two holes deducted from each angle for net section.

† Top and bottom flanges should have $3\frac{1}{2}$ x 3 x $\frac{5}{16}$ $\angle$s.

These errors were due to errors in original stresses. They were not noticed until after the design had been used in future chapters and the sections above will not be revised. The areas of cross section, and moments of inertia of the above girders about an axis midway between the centers of gravity of flanges will be required in future chapters and these calculations are given in the following table.

Girder.	Area, 4∠s.	Area, Web.	Total Area.	d.	I. Web.	I-4∠s. Primary.	I-4∠s. Ad^2 Secondary.	Total I.
A–0	13.72	9.95	23.67	12.5	582	13	2,145	2,740
A–1	12.20	8.13	20.33	12.5	458	13	1,907	2,378
A–2	9.64	8.13	17.77	12.5	458	7	1,507	1,972
A–3	8.70	8.30	17.00	12.5	484	6	1,360	1,850
A–4	7.76	6.71	14.47	10.0	259	6	776	1,041

CHAPTER III.

STRESSES IN PORTAL BRACED BUILDINGS—ENTIRE STRUCTURE ELASTIC.

In this chapter there is developed a method of determining the stresses in a plain plate girder portal braced building for all types of loading on the assumption that the entire structure is elastic. First the general case is developed and then special formulae and methods are given for a structure containing only two columns in a transverse section.

The following assumptions are involved in this discussion:

(*a*) That the connections of the girders to the columns are sufficiently rigid to maintain the column in a straight line for the full depth of the girder and that, as a consequence, the deformation curves of the girders and columns are normal to each other at their intersections.

(*b*) That the curvature of the columns and girders is considered as having no effect on their axial lengths.

(*c*) That the columns at their anchorages will always be maintained in a fixed vertical direction.

(*d*) That the elastic limit of the material will never be exceeded.

(*e*) That the material shall be uniform throughout the structure.

(*f*) The increase of bending moment leverage due to the deflection of columns and girders is neglected.

(*g*) The mid depth lines of girders are considered as their neutral axes.

These assumptions, it is believed, are all rational and non conflicting.

In order to make the method about to be developed more readily understood the following outline is given:

The fundamental differential equation of the elastic line of any member under stress is

$$EI\frac{d^2y}{dx^2} = Mx.$$

The building is considered as made up of individual members

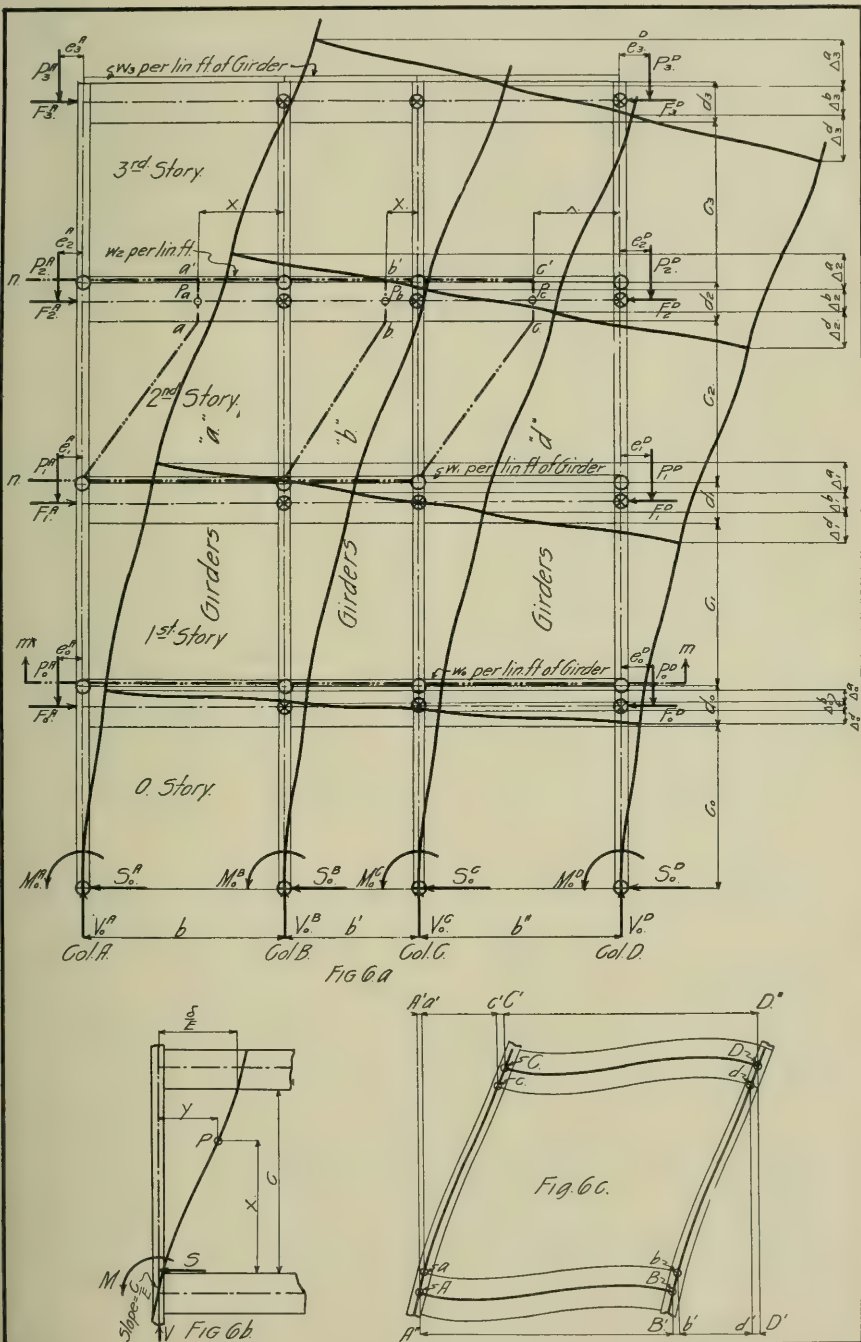

w₃ per lin ft of Girder
3rd Story
w₂ per lin ft
2nd Story
w₁ per lin ft of Girder
Girders
Girders
Girders
1st Story
w₀ per lin ft of Girder
0. Story
Col. A.
Col. B.
Col. C.
Col. D.
Fig. 6c.

FIG 6.a

FIG 6b.

(columns and girders) rigidly connected to each other, and the above equation successively applied to each member. First, certain conditions of the problem are used in eliminating and evaluating the constants of integration of the elastic lines of all members. Then the remaining unused conditions are developed into three independent equations per panel of the cross section of the building. These equations are verbally expressed as follows:

Equations A are best understood by a reference to Fig. 6, *c*, which represents a distorted panel taken out of the structure. The equation is simply

$$A'D'' = A''D'$$

or

$$A'a' + a'c' + c'C' + C'D'' = A''B' + B'b' + b'd' + d'D',$$

in which $A'a'$, $c'C'$, $B'b'$, and $d'D'$ are equal to the half depth of the girder times the slope of the corresponding column at the points A, C, B, and D respectively; $a'c'$ and $b'd'$ represent the deflection of the columns ac and bd respectively; $A''B'$ and $C'D''$ represent the original unstrained length of the neutral axes of the girders minus the shortening due to axial compression in the girder.

Equations B.—The slope of the elastic line of any girder (inclination to the horizontal) at the end of the girder will be equal to the slope of the elastic line of the column (inclination to the vertical) connecting thereto. There of course exists such a relation for each end of the girder, but one of these conditions has already been used to evaluate a constant of integration.

Equations C.—Considering the origin of coordinates for the elastic line of a girder as located on the neutral axis and at one end of the girder, the vertical deflection of the other end of the girder will be equal to the total difference in the change of length of the two columns connecting to the girder in the distance from the column anchorages to the neutral axis of the girder. These quantities are shown graphically in Fig. 6, *a*, in which they are marked Δ.

Now, starting at the bottom of the building, by means of these equations three of the unknowns of the problem are eliminated from each successive panel until the top of the building is reached. The equations A, B, and C for the top panels may then and not till then be solved for the unknowns of the top floor panels. Substitution

may then be made in the lower floors successively until, having reached the bottom panel, all quantities are known. Each panel contains three unknowns in terms of which all other quantities may be expressed and as seen above each panel furnishes the necessary equations for their elimination.

The origins of coordinates are taken as follows:

For All Columns.—Separate origins are taken for each column section; they are located at the foot of the column section (length $= c$). The coordinates are measured vertically and horizontally, x being considered positive upwards and y positive to the right.

For all Girders.—Origins are located on the intersections of the neutral axes with the axis of the column connecting on the right end of the girders. Coordinates are measured horizontally and vertically, x being considered positive to the left and y positive upwards.

All column origins are shown on Fig. 6, a; thus $\oplus$.

All girder origins are shown on Fig. 6, a; thus $\otimes$.

EXPRESSIONS GIVING THE VALUES OF THE VARIOUS PROPERTIES OF THE STRUCTURE UNDER LOAD.

Slopes and Deflections of Columns.—Referring to Fig. 6, b, which represents in general a column section from any part of the building, the differential equation of the elastic line of any column section is

$$E\frac{d^2y}{dx^2} = \frac{M}{I} - \frac{S}{I}x$$

(cf. Chapter II). First integration gives

$$E\frac{dy}{dx} = \frac{M}{I}x - \frac{S}{2I}x^2 + K$$

where K is a constant of integration. Second integration gives

$$Ey = \frac{M}{2I}x^2 - \frac{S}{6I}x^3 + Kx + K'$$

where K' is a constant of integration.

But when $x = 0$, $E\,dy/dx = C$ (see Fig. 6, b, and "Notation"), hence $K = C$ and

$$E\frac{dy}{dx} = \frac{M}{I}x - \frac{S}{2I}x^2 + C.$$

Now, making $x = c$ in this equation the value of C for the column section above is found to be $Mc/I - Sc^2/2I + C$. For the basement sections $C = 0$, since the columns are here fixed in a vertical direction. By assigning the proper subscripts and exponents to the terms of this formulae values of C for all column sections are written as follows:

For Columns A.

$$C_0^A = 0,$$

$$C_1^A = \frac{M_0^A C_0}{I_0^A} - \frac{S_0^A C_0^2}{2I_0^A},$$

$$C_2^A = \frac{M_1^A C_1}{I_1^A} - \frac{S_1^A C_1^2}{2I_1^A} + C_1^A,$$

$$C_3^A = \frac{M_2^A C_2}{I_2^A} - \frac{S_2^A C_2^2}{2I_2^A} + C_2^A.$$

For Columns B.

$$C_0^B = 0,$$

$$C_1^B = \frac{M_0^B C_0}{I_0^B} - \frac{S_0^B C_0^2}{2I_0^B},$$

$$C_2^B = \frac{M_1^B C_1}{I_1^B} - \frac{S_1^B C_1^2}{2I_1^B} + C_1^B,$$

$$C_3^B = \frac{M_2^B C_2}{I_2^B} - \frac{S_2^B C_2^2}{2I_2^B} + C_2^B.$$

For Columns C.

$$C_0^C = 0,$$

$$C_1^C = \frac{M_0^C C_0}{I_0^C} - \frac{S_0^C C_0^2}{2I_0^C},$$

$$C_2^C = \frac{M_1^C C_1}{I_1^C} - \frac{S_1^C C_1^2}{2I_1^C} + C_1^C,$$

$$C_3^C = \frac{M_2^C C_2}{I_2^C} - \frac{S_2^C C_2^2}{2I_2^C} + C_2^C.$$

For Columns D.

$$C_0^D = 0,$$

$$C_1^D = \frac{M_0^D C_0}{I_0^D} - \frac{S_0^D C_0^2}{2I_0^D},$$

$$C_2^D = \frac{M_1^D C_1}{I_1^D} - \frac{S_1^D C_1^2}{2I_1^D} + C_1^D,$$

$$C_3^D = \frac{M_2^D C_2}{I_2^D} - \frac{S_2^D C_2^2}{2I_2^D} + C_2^D.$$

Now when $x = 0$, $y = 0$, and hence $K' = 0$ and

$$Ey = \frac{M}{2I}x^2 - \frac{S}{6I}x^3 + Cx.$$

In this equation, when $x = c$, $Ey = \delta$ (see "notation") $= Mc^2/2I - sc^3/6I + Cc$. Assigning proper subscripts and exponents as above, values of δ for all column sections are written as follows:

For Columns A.

$$\delta_0^A = \frac{M_0^A C_0^2}{2I_0^A} - \frac{S_0^A C_0^3}{6I_0^A},$$

$$\delta_1^A = \frac{M_1^A C_1^2}{2I_1^A} - \frac{S_1^A C_1^3}{6I_1^A} + C_1^A c_1,$$

For Columns B.

$$\delta_0^B = \frac{M_0^B C_0^2}{2I_0^B} - \frac{S_3^B C_0^3}{6I_0^B},$$

$$\delta_1^B = \frac{M_1^B C_1^2}{2I_1^B} - \frac{S_1^B C_1^3}{6I_1^B} + C_1^B c_1,$$

$$\delta_2^A = \frac{M_2^A C_2^2}{2I_2^A} - \frac{S_2^A C_2^3}{6I_2^A} + C_2^A c_2, \quad \delta_2^B = \frac{M_2^B C_2^2}{2I_2^B} - \frac{S_2^B C_2^3}{6I_2^B} + C_2^B c_2,$$

$$\delta_3^A = \frac{M_3^A C_3^2}{2I_3^A} - \frac{S_3^A C_3^3}{6I_3^A} + C_3^A c_3. \quad \delta_3^B = \frac{M_3^B C_3^2}{2I_3^B} - \frac{S_3^B C_3^3}{6I_3^B} + C_3^B c_3.$$

For Columns C. For Columns D.

$$\delta_0^C = \frac{M_0^C C_0^2}{2I_0^C} - \frac{S_0^C C_0^3}{6I_0^C}, \quad \delta_0^D = \frac{M_0^D C_0^2}{2I_0^D} - \frac{S_0^D C_0^3}{6I_0^D},$$

$$\delta_1^C = \frac{M_1^C C_1^2}{2I_1^C} - \frac{S_1^C C_1^3}{6I_1^C} + C_1^C c_1, \quad \delta_1^D = \frac{M_1^D C_1^2}{2I_2^D} - \frac{S_1^D C_1^3}{6I_1^D} + C_1^D c_1,$$

$$\delta_2^C = \frac{M_2^C C_2^2}{2I_2^C} - \frac{S_2^C C_2^3}{6I_2^C} + C_2^C c_2, \quad \delta_2^D = \frac{M_2^D C_2^2}{2I_2^D} - \frac{S_2^D C_2^3}{6I_2^D} + C_2^D c_2,$$

$$\delta_3^C = \frac{M_3^C C_3^2}{2I_3^C} - \frac{S_3^C C_3^3}{6I_3^C} + C_3^C c_3. \quad \delta_3^D = \frac{M_3^D C_3^2}{2I_3^D} - \frac{S_3^D C_3^3}{6I_3^D} + C_3^D c_3.$$

Axial Shortening of Girders.—For an axial thrust H the shortening in the length b will equal Hb/AE or E times this shortening $= \lambda = Hb/A$. Values of λ for all girders are given as follows:

For Girders "a." For Girders "b." For Girders "d."

$$\lambda_0^a = \frac{H_0^a b}{A_0^a}, \quad \lambda_0^b = \frac{H_0^b b'}{A_0^b}, \quad \lambda_0^d = \frac{H_0^d b''}{A_0^d},$$

$$\lambda_1^a = \frac{H_0^a b}{A_1^a}, \quad \lambda_1^b = \frac{H_1^b b'}{A_1^b}, \quad \lambda_1^d = \frac{H_1^d b''}{A_1^d},$$

$$\lambda_2^a = \frac{H_2^a b}{A_2^a}, \quad \lambda_2^b = \frac{H_2^b b'}{A_2^b}, \quad \lambda_2^d = \frac{H_2^b b''}{A_2^d},$$

$$\lambda_3^a = \frac{H_3^a b}{A_3^a}. \quad \lambda_3^b = \frac{H_3^b b'}{A_3^b}. \quad \lambda_3^d = \frac{H_3^d b''}{A_3^d}.$$

Axial Stresses in Girders.—Considering sections such as $naa'n$, $nbb'n$, and $ndd'n$ and equating the sums of the horizontal forces acting on the sections cut to zero the following values of H may be written.

For Girders "a." For Girders "b."

$$H_0^a = S_1^A - S_0^A + F_0^A, \quad H_0^b = S_1^A + S_1^B - S_0^A - S_0^B + F_0^A,$$

$$H_1^a = S_2^A - S_1^A + F_1^A, \quad H_1^b = S_2^A + S_2^B - S_1^A - S_1^B + F_1^A,$$

$$H_2^a = S_3^A - S_2^A + F_2^A, \quad H_2^b = S_3^A + S_3^B - S_2^A - S_2^B + F_2^A,$$

$$H_3^a = - S_3^A + F_3^A. \quad H_3^b = - S_3^A - S_3^B + F_3^A.$$

For Girders "*d*."

$$H_0^d = S_1^A + S_1^B + S_1^C - S_0^A - S_0^B - S_0^C + F_0^A,$$
$$H_1^d = S_2^A + S_2^B + S_2^C - S_1^A - S_1^B - S_1^C + F_1^A,$$
$$H_2^d = S_3^A + S_3^B + S_3^C - S_2^A - S_2^B - S_2^C + F_2^A,$$
$$H_3^d = - S_3^A - S_3^B - S_3^C + F_3^A.$$

Axial Stresses in Columns.—In considering the loads on this structure it is to be noted that the wind is taken as acting on each side simultaneously; the purpose of this is to make the equations perfectly general, so that they may be used for wind on either side by merely dropping the terms involving wind on the other side. Passing horizontal planes *mm*, Fig. 6, *a*, through the origins of coordinates for the columns and taking as centre of moments the intersection of these planes with Col. *D*, let *X* be the moment about this point of all the given external forces acting on the upper portion of the structure cut by *mm* (positive clockwise) and let *Y* be the sum of all the vertical forces or components acting downward on this portion of the structure. Now, using this center of moments there is obtained

$$X + V^A(b + b' + b'') + V^B(b' + b'') + V^Cb'' - (M^A + M^B + M^C + M^D) = 0$$

or

$$V^A = \frac{(M^A + M^B + M^C + M^D) - V^B(b' + b'') - V^Cb'' - X}{b + b' + b''}.$$

Also

$$V^D = Y - V^A - V^B - V^C$$
$$= - \frac{(M^A + M^B + M^C + M^D) - V^Bb - V^C(b + b') + Y(b + b' + b'') + X}{b + b' + b''}.$$

Therefore

$$V_0^A = \frac{(M_0^A + M_0^B + M_0^C + M_0^D) - V_0^B(b' + b'') - V_0^Cb'' - X_0}{b + b' + b''},$$

$$V_1^A = \frac{(M_1^A + M_1^B + M_1^C + M_1^A) - V_1^B(b' + b'') - V_1^Cb'' - X_1}{b + b' + b''},$$

$$V_2^A = \frac{(M_2^A + M_2^B + M_2^C + M_2^D) - V_2^B(b' + b'') - V_2^C b'' - X_2}{b + b' + b''},$$

$$V_3^A = \frac{(M_3^A + M_3^B + M_3^C + M_3^D) - V_3^B(b' + b'') - V_3^C b'' - X_3}{b + b' + b''},$$

$$V_0^D = \frac{- (M_0^A + M_0^B + M_0^C + M_0^D) - V_0^B b - V_0^C(b + b') + Y_0(b + b' + b'') + X_0}{b + b' + b''},$$

$$V_1^D = \frac{- (M_1^A + M_1^B + M_1^C + M_1^D) - V_1^B b - V_1^C(b + b') + Y_1(b + b' + b'') + X_1}{b + b' + b''},$$

$$V_2^D = \frac{- (M_2^A + M_2^B + M_2^C + M_2^D) - V_2^B b - V_2^C(b + b') + Y_2(b + b' + b'') + X_2}{b + b' + b'',},$$

$$V_3^D = \frac{- (M_3^A + M_3^B + M_3^C + M_3^D) - V_3^B b - V_3^C(b + b') + Y_3(b + b' + b'') + X_3}{b + b' + b''.},$$

This shows that, no matter how many columns in a cross section the axial stress in two of them may always be expressed in terms of the others and the other unknowns. V^B and V^C must be solved for in the regular course of solution as outlined.

Axial Shortening of Column Sections.—From centre of floor girder to centre of floor girder. Since the thrust is axial the shortening of the *n*th story section will equal

$$\frac{V_n(c_n + \tfrac{1}{2}d_{n-1} + \tfrac{1}{2}d_n)}{A_n E}$$

or E times the shortening =

$$\alpha_n = \frac{V_n(c_n + \tfrac{1}{2}d_{n-1} + \tfrac{1}{2}d_n)}{A_n}.$$

Values of α are given as follows:

For Column A.

$$\alpha_0^A = \frac{V_0^A(c_0 + \tfrac{1}{2}d_0)}{A_0^A},$$

For Column B.

$$\alpha_0^B = \frac{V_0^B(c_0 + \tfrac{1}{2}d_0)/}{A_0^B},$$

$$\alpha_1^A = \frac{V_1^A(c_1 + \frac{1}{2}d_0 + \frac{1}{2}d_1)}{A_1^A}, \quad \alpha_1^B = \frac{V_1^B(c_1 + \frac{1}{2}d_0 + \frac{1}{2}d_1)}{A_1^B},$$

$$\alpha_2^A = \frac{V_2^A(c_2 + \frac{1}{2}d_1 + \frac{1}{2}d_2)}{A_2^A}, \quad \alpha_2^B = \frac{V_2^B(c_2 + \frac{1}{2}d_1 + \frac{1}{2}d_2)}{A_2^B},$$

$$\alpha_3^A = \frac{V_3^A(c_3 + \frac{1}{2}d_2 + \frac{1}{2}d_3)}{A_3^A}. \quad \alpha_3^B = \frac{V_3^B(c_3 + \frac{1}{2}d_2 + \frac{1}{2}d_3)}{A_3^B}.$$

For Column C. For Column D.

$$\alpha_0^C = \frac{V_0^C(c_0 + \frac{1}{2}d_0)}{A_0^C}, \quad \alpha_0^D = \frac{V_0^D(c_0 + \frac{1}{2}d_0)}{A_0^D},$$

$$\alpha_1^C = \frac{V_1^C(c_1 + \frac{1}{2}d_0 + \frac{1}{2}d_1)}{A_1^C}, \quad \alpha_1^D = \frac{V_1^D(c_1 + \frac{1}{2}d_0 + \frac{1}{2}d_1)}{A_1^D},$$

$$\alpha_2^C = \frac{V_2^C(c_2 + \frac{1}{2}d_1 + \frac{1}{2}d_2)}{A_2^C}, \quad \alpha_2^D = \frac{V_2^D(c_2 + \frac{1}{2}d_1 + \frac{1}{2}d_2)}{A_2^D},$$

$$\alpha_3^C = \frac{V_3^C(c_3 + \frac{1}{2}d_2 + \frac{1}{2}d_3)}{A_3^C}. \quad \alpha_3^D = \frac{V_3(c_3 + \frac{1}{2}d_2 + \frac{1}{2}d_3)}{A_3^D}.$$

Values of Δ.—Δ, to be positive, will equal E times the total shortening of the right hand column minus E times the total shortening of the left hand column. Thus, starting at the bottom of the building the values of Δ are:

For Girders "a." For Girders "b." For Girders "d."

$$\Delta_0^a = \alpha_0^B - \alpha_0^A, \quad \Delta_0^b = \alpha_0^C - \alpha_0^B, \quad \Delta_0^d = \alpha_0^D - \alpha_0^C,$$

$$\Delta_1^a = \alpha_1^B - \alpha_1^A + \Delta_0^a, \quad \Delta_1^b = \alpha_1^C - \alpha_1^B + \Delta_0^b. \quad \Delta_1^d = \alpha_1^D - \alpha_1^C + \Delta_0^d,$$

$$\Delta_2^a = \alpha_2^B - \alpha_2^A + \Delta_1^a, \quad \Delta_2^b = \alpha_2^C - \alpha_2^B + \Delta_1^b, \quad \Delta_2^d = \alpha_2^D - \alpha_2^C + \Delta_1^d,$$

$$\Delta_3^a = \alpha_3^B - \alpha_3^A + \Delta_2^a. \quad \Delta_3^b = \alpha_3^C - \alpha_3^B + \Delta_2^b. \quad \Delta_3^d = \alpha_3^D - \alpha_3^C + \Delta_2^d.$$

Slopes and Elastic Lines of the Girders.—Referring to Fig. 6, a, pass planes $naa'n$, $nbb'n$, and $ncc'n$ as was done in Chapter II. Taking moments about the points Pa, Pb, and Pd respectively the following differential equations of the elastic lines of the girders are found:

For girder a–2:

$$E\frac{d^2y}{dx^2}=\frac{1}{I_2^a}\left\{(V_2^A-V_3^A)(b-x)+\left[S_2^A(c_2+\tfrac{1}{2}d_2)+S_3^A\frac{d_2}{2}-M_2^A+M_3^A\right]\right.$$
$$\left.-\frac{w_2(b-x)^2}{2}-P_2^A(b+e_2^A-x)\right\}.$$

For girder b–2:

$$E\frac{d^2y}{dx^2}=\frac{1}{I_2^b}\left\{(V_2^A-V_3^A)b+(V_2^A-V_3^A+V_2^B-V_3^B)(b'-x)\right.$$
$$+[(S_2^A+S_2^B)(c_2+\tfrac{1}{2}d_2)+(S_3^A+S_3^B)\frac{d_2}{2}-M_2^A-M_2^B+M_3^A+M_3^B]$$
$$\left.-\frac{w_2b^2}{2}-w_2\left[b(b'-x)+\frac{(b'-x)^2}{2}\right]-P_2^A(b+e_2^A)-P_2^A(b'-x)\right\}.$$

For girder d–2:

$$E\frac{d^2y}{dx^2}=\frac{1}{I_2^d}\left\{(V_2^A-V_3^A)(b+b')+(V_2^A-V_3^A+V_2^B-V_3^B)b'\right.$$
$$+(V_2^A-V_3^A+V_2^B-V_3^B+V_2^C-V_3^C)(b''-x)$$
$$+\left[(S_2^A+S_2^B+S_2^C)(c_2+\tfrac{1}{2}d_2)+(S_3^A+S_3^B+S_3^C)\frac{d_2}{2}\right.$$
$$\left.-M_2^A-M_2^B-M_2^C+M_3^A+M_3^B+M_3^C\right]-\frac{w_2(b+b')^2}{2}$$
$$\left.-w_2\left[(b+b')(b''-x)+\frac{(b''-x)^2}{2}\right]-P_2^A(b+b'+e_2^A)-P_2^A(b''-x)\right\}.$$

These expressions may be very much simplified by writing them as follows:

For girder a–2:

$$E\frac{d^2y}{dx^2}=Q_2^a+R_2^a(b-x)-\frac{w_2(b-x)^2}{2I_2^a}.$$

For girder b–2:

$$E\frac{d^2y}{dx^2}=Q_2^b+R_2^b(b'-x)-\frac{w_2(b'-x)^2}{2I_2^b}.$$

For girder d–2:

$$E\frac{d^2y}{dx^2}=Q_2^d+R_2^d(b''-x)-\frac{w_2(b''-x)^2}{2I_2^b}.$$

The values of Q in these equations are:

$$Q_2^a = \frac{1}{I_2^a}\left\{ S_2^A(c_2 + \tfrac{1}{2}d_2) + S_3^A\frac{d_2}{2} - M_2^A + M_3^A - P_2^A e_2^A \right\},$$

$$Q_2^b = \frac{1}{I_2^b}\left\{ (S_2^A + S_2^B)(c_2 + \tfrac{1}{2}d_2) + (S_3^A + S_3^B)\frac{d_2}{2} \right.$$
$$\left. - M_2^A - M_2^B + M_3^A + M_3^B - P_2^A(b + e_2^A) - \frac{w_2 b^2}{2} + (V_2^A - V_3^A)b \right\},$$

$$Q_2^d = \frac{1}{I_2^d}\left\{ (S_2^A + S_2^B + S_2^C)(c_2 + \tfrac{1}{2}d_2) + (S_3^A + S_3^B + S_3^C)\frac{d_2}{2} \right.$$
$$-M_2^A - M_2^B - M_2^C + M_3^A + M_3^B + M_3^C - P_2^A(b + b' + e_2^A) - \frac{w_2(b + b')^2}{2}$$
$$\left. + (V_2^A - V_3^A)(b + b') + (V_2^A - V_3^A + V_2^B - V_3^B)b' \right\}.$$

The values of R are:

$$R_2^a = \frac{1}{I_2^a}\{(V_2^A - V_3^A) - P_2^A\},$$

$$R_2^b = \frac{1}{I_2^b}\{(V_2^A - V_3^A + V_2^B - V_3^B) - P_2^A - w_2 b\},$$

$$R_2^d = \frac{1}{I_2^d}\{(V_2^A - V_3^A + V_2^B - V_3^B + V_2^C - V_3^C) - P_2^A - w_2(b + b')\}.$$

Now the differential equations of the elastic lines for any other story may be written by merely changing the subscripts to correspond with the story.

Integrating the differential equations of the elastic line there results:

For girder a–2.

$$E\frac{dy}{dx} = (Q_2^a + R_2^a b)x - R_2^a\frac{x^2}{2} + \frac{w_2(b - x)^3}{6I_2^a} + K_2^a$$

where K_2^a is a constant of integration.

For girder b–2.

$$E\frac{dy}{dx} = (Q_2^b + R_2^b b')x - R_2^b\frac{x^2}{2} + \frac{w_2(b' - x)^3}{6I_2^b} + K_2^b$$

where K_2^b is a constant of integration.

For girder d–2.

$$E\frac{dy}{dx} = (Q_2^d + R_2^d b'')x - R_2^b\frac{x^2}{2} + \frac{w_2(b'' - x)^3}{6I^d} + K_2^d$$

where K_2^d is a constant of integration.

But when $x = 0$ for girder a–2,

$$E\frac{dy}{dx} = C_3^B$$

and therefore

$$K_2^A = C_3^B - \frac{w_2 b^3}{6I_2^a}.$$

Also, when $x = 0$ for girder b–2,

$$E\frac{dy}{dx} = C_3^C,$$

and therefore

$$K_2^b = C_3^C - \frac{w_2 b'^3}{6I_2^b}.$$

Also, when $x = 0$ for girder d–2,

$$E\frac{dy}{dx} = C_3^D,$$

and therefore

$$K_2^d = C_3^D - \frac{w_2 b''^3}{6I_2^d}.$$

Thus the *slope equations for the elastic lines of the girders* become:
For girder a–2,

$$E\frac{dy}{dx} = (Q_2^a + R_2^a b)x - R_2^a\frac{x^2}{2} + \frac{w_2(b - x)^3}{6I_2^a} + C_3^B - \frac{w_2 b^3}{6I_3^A}.$$

For girder b–2,

$$E\frac{dy}{dx} = (Q_2^b + R_2^b b')x - R_2^b\frac{x^2}{2} + \frac{w_2(b' - x)^3}{6I_2^b} + C_3^C - \frac{w_2 b'^3}{6I_2^b}.$$

For girder d–2,

$$E\frac{dy}{dx} = (Q_2^d + R_2^d b'')x - R_2^d\frac{x^2}{2} + \frac{w_2(b'' - x)^3}{6I_2^d} + C_3^D - \frac{w_2 b''^3}{6I_2^d}.$$

Integrating again there results:
For girder a–2,

$$Ey = (Q_2^a + R_2^a b)\frac{x^2}{2} - R_2^a\frac{x^3}{6} - \frac{w_2(b-x)^4}{24I_2^a} + \left(C_3^B - \frac{w_2 b^3}{6I_2^a}\right)x + L_2^a,$$

where L_2^a is a constant of integration.
For girder b–2,

$$Ey = (Q_2^b + R_2^b b')\frac{x^2}{2} - R_2^b\frac{x^3}{6} - \frac{w_2(b'-x)^4}{24I_2^b} + \left(C_3^C - \frac{w_2 b'^3}{6I_2^b}\right)x + L_2^b,$$

where L_2^b is a constant of integration.
For girder d–2,

$$Ey = (Q_2^d + R_2^d b'')\frac{x^2}{2} - R_2^d\frac{x^3}{6} - \frac{w_2(b''-x)^4}{24I_2^d} + \left(C_3^D - \frac{w_2 b''^3}{6I_2^d}\right)x + L_2^d,$$

where L_2^d is a constant of integration.

But, in all cases, when $x = 0$, $y = 0$ hence

$$L_2^a = \frac{w_2 b^4}{24I_2^a}, \quad L_2^b = \frac{w_2 b'^4}{24I_2^b},$$

and

$$L_2^d = \frac{w_2 b''^4}{24I_2^d}.$$

Thus the *equations of the elastic lines of the girders* become:
For girder a–2,

$$Ey = (Q_2^a + R_2^a b)\frac{x^2}{2} - R_2^a\frac{x^3}{6} - \frac{w_2(b-x)^4}{24I_2^a} + \left(C_3^B - \frac{w_2 b^3}{6I_2^a}\right)x + \frac{w_2 b^4}{24I_2^a}.$$

For girder b–2,

$$Ey = (Q_2^b + R_2^b b')\frac{x^2}{2} - R_2^b\frac{x^3}{6} - \frac{w_2(b'-x)^4}{24I_2^b} + \left(C_3^C - \frac{w_2 b'^3}{6I_2^b}\right)x + \frac{w_2 b'^4}{24I_2^b}.$$

For girder d–2,

$$Ey = (Q_2^d + R_2^d b'')\frac{x^2}{2} - R_2^d\frac{x^3}{6} - \frac{w_2(b''-x)^4}{24I_2^d} + \left(C_3^D - \frac{w_2 b''^3}{6I_2^d}\right)x + \frac{w_2 b''^4}{24I_2^d}.$$

EQUATIONS FOR THE DETERMINATION OF THE UNKNOWNS.

The properties and elastic lines of all members of the structure have now been given. The equations whose solution determines all the unknowns are as follows:

Equation A.—Referring back to page 38, equation A, in general, is given as follows:

$$A'a' + a'c' + c'C' + C'D'' = A''B' + B'b' + b'd' + d'D'.$$

But

$$A'a',\ c'C',\ B'b',\ \text{and}\ \ d'D' = \frac{C}{E} \times \frac{d}{2};$$

$$a'c'\ \ \text{and}\ \ b'd' = \frac{\delta}{E};$$

and

$$A''B'\ \ \text{and}\ \ C'D'' = b - \frac{\lambda}{E}.$$

There will be such an equation for each panel of the cross section and, in order that any one of these equations may be readily referred to, the equations for panels included between Columns A and B will be known as equations A^a; for the panels included between Columns B and C they will be known as equations A^b; for those between Columns C and D they will be known as equations A^d. These equations are as follows:

Equations A^a.

$$\delta_0^A - \delta_0^B + \frac{d_0}{2}(C_1^A - C_1^B) - \lambda_0^a = 0,$$

$$\delta_1^A - \delta_1^B + \frac{d_1}{2}(C_2^A - C_2^B) + \frac{d_0}{2}(C_1^A - C_1^B) + \lambda_0^a - \lambda_1^a = 0,$$

$$\delta_2^A - \delta_2^B + \frac{d_2}{2}(C_3^A - C_3^B) + \frac{d_1}{2}(C_2^A - C_2^B) + \lambda_1^a - \lambda_2^a = 0,$$

$$\delta_3^A - \delta_3^B + \frac{d_3}{2}(C_4^A - C_4^B) + \frac{d_2}{2}(C_3^A - C_3^B) + \lambda_2^a - \lambda_3^a = 0.$$

Equations A^b.

$$\delta_0^B - \delta_0^C + \frac{d_0}{2}(C_1^B - C_1^C) - \lambda_0^b = 0,$$

$$\delta_1^B - \delta_1^C + \frac{d_1}{2}(C_2^B - C_2^C) + \frac{d_0}{2}(C_1^B - C_1^C) + \lambda_0^b - \lambda_1^b = 0,$$

$$\delta_2^B - \delta_2^C + \frac{d_2}{2}(C_3^B - C_3^C) + \frac{d_1}{2}(C_2^B - C_2^C) + \lambda_1^b - \lambda_2^b = 0,$$

$$\delta_3^B - \delta_3^C + \frac{d_3}{2}(C_4^B - C_4^C) + \frac{d_2}{2}(C_3^B - C_3^C) + \lambda_2^b - \lambda_3^b = 0.$$

Equations A^d.

$$\delta_0^C - \delta_0^D + \frac{d_0}{2}(C_1^C - C_1^D) - \lambda_0^d = 0,$$

$$\delta_1^C - \delta_1^D + \frac{d_1}{2}(C_2^C - C_2^D) + \frac{d_0}{2}(C_1^C + C_2^D) + \lambda_0^d - \lambda_1^d = 0,$$

$$\delta_2^C - \delta_2^D + \frac{d_2}{2}(C_3^C - C_3^D) + \frac{d_1}{2}(C_2^C - C_2^D) + \lambda_1^d - \lambda_2^d = 0,$$

$$\delta_3^C - \delta_3^D + \frac{d_3}{2}(C_4^C - C_4^D) + \frac{d_2}{2}(C_3^C - C_3^D) + \lambda_2^d - \lambda_3^d = 0.$$

Equations B.—When x is made equal to b, b', and b'' respectively in the *slope equations of the elastic lines of the girders* above $E \cdot dy/dx$ equals C^A, C^B, and C^C respectively. Now, designating equations B as above, *i. e.*, B^a for girders "a," B^b for girders "b" and B^d for girders "d," these equations may be expressed thus:

Equations B^a ($x = b$).	Equations B^b ($x = b'$).	Equations B^d ($x = b''$).
$E\frac{dy}{dx} = C_1^A,$	$E\frac{dy}{dx} = C_1^B,$	$E\frac{dy}{dx} = C_1^C,$
$E\frac{dy}{dx} = C_2^A,$	$E\frac{dy}{dx} = C_2^B,$	$E\frac{dy}{dx} = C_2^C,$
$E\frac{dy}{dx} = C_3^A,$	$E\frac{dy}{dx} = C_3^B,$	$E\frac{dy}{dx} = C_3^C,$
$E\frac{dy}{dx} = C_4^A.$	$E\frac{dy}{dx} = C_4^B.$	$E\frac{dy}{dx} = C_4^C.$

Equations C.—When x is made equal to b, b', and b'' respectively in the *equations of the elastic lines of the girders* above Ey equals Δ^a, Δ^b, and Δ^d respectively. Now, designating equations C as above, *i. e.*, C^a for girders "a," C^b for girders "b" and C^d for girders "d" these equations may be expressed thus:

Equations C^a ($x = b$).	Equations C^b ($x = b'$).	Equations C^d ($x = b''$).
$Ey = \Delta_0^a,$	$Ey = \Delta_0^b,$	$Ey = \Delta_0^d,$
$Ey = \Delta_1^a,$	$Ey = \Delta_1^b,$	$Ey = \Delta_1^d,$
$Ey = \Delta_2^a,$	$Ey = \Delta_2^b,$	$Ey = \Delta_2^d,$
$Ey = \Delta_3^a.$	$Ey = \Delta_3^b.$	$Ey = \Delta_3^d.$

Now, if the expressions already given for the different terms comprised in these three sets of equations be substituted in the equations there will result, even when reduced to as simple forms as possible, very long and forbidding equations. A systematic method of handling these combined expressions and the three sets of equations A, B, and C must be devised before a solution can be comprehensively considered. Each story contains *nine* unknowns, or three per panel; these are M^A, S^A, V^B, M^B, S^B, V^C, and M^C, S^C, M^D. In addition to keeping these *nine unknowns* in the equations it is found much simpler to include also the dependent quantities C^A, C^B, C^C, C^D, and Δ^a, Δ^b, Δ^d. The reason for this will be understood as the method becomes clear. Now, each of the *expressions* as well as each of the *equations A, B and C* involve more or less of these terms. The coefficients of these terms will in many cases be long expressions of known quantities and these coefficients will be represented in this discussion by the letters of the alphabet and the values of these coefficients may be readily written by reference to the expressions in which they occur. The *most general equation for the nth story*, which will apply to *all expressions* as well as *all equations* is:

$$\begin{aligned} Z_n = {} & a_n^Z M_n^A + b_n^Z M_n^B + c_n^Z M_n^C + d_n^Z M_n^D + e_n^Z M_{n+1}^A + f_n^Z M_{n+1}^B \\ & + g_n^Z M_{n+1}^C + h_n^Z M_{n+1}^D + i_n^Z S_n^A + j_n^Z S_n^B + k_n^Z S_n^C + l_n^Z S_{n+1}^A + m_n^Z S_{n+1}^B \\ & + n_n^Z S_{n+1}^C + o_n^Z V_n^B + p_n^Z V_n^C + q_n^Z V_{n+1}^B + r_n^Z V_{n+1}^C + s_n^Z C_n^A + t_n^Z C_n^B \\ & + u_n^Z C_n^C + v_n^Z C_n^D + w_n^Z \Delta_n^a + x_n^Z \Delta_n^b + y_n^Z \Delta_n^d + P_n^Z S_{n-1}^A + Q_n^Z S_{n-1}^B \\ & + R_n^Z S_{n-1}^C + (z_n^Z = \text{Constant Term}). \end{aligned}$$

In this equation Z_n represents the terms whose value is to be expressed in terms of the unknowns. Thus, for the expression for C_2^B, $Z_n = C_2^B$ and the exponents "Z" used with all coefficients shown above would be $C - B$; therefore, referring back to the expressions for C (page 40)

$$C_2^B = b_1^{C-B} M_1^B + j_1^{C-B} S_1^B + C_1^B$$

in which, of course,

$$b_1^{C-B} = \frac{c_1}{I^B}$$

and

$$j_1^{C-B} = -\frac{c_1^2}{2I_1^B}.$$

For equations A, B, and C, Z_n always equals zero and for the exponents "z" the letters A, B, and C will be used respectively. It will be noted that S_n^D does not appear in the general equation above. This quantity is eliminated by writing

$$S_n^D = \Sigma F - S_n^A - S_n^B - S_n^C$$

since the sum of the horizontal column shears "S" in any story must equal the total wind shear on a section of the building cutting these columns. The equations of the form given above will be called "symbolic" equations and these equations are now given for all expressions and equations of the structure in Plates, 1, 2 and 3.

By comparing the expressions and equations, as already given, with these symbolic forms the values of the coefficients in the symbolic equations are readily found. It will be noticed that in the general expression covering all symbolic equations the value of the subscript n of Z_n will be the same as that of the same subscript occurring with all terms of the equation except as above shown for the expressions for values of C, for which it might have been more properly written Z_{n+1}. The values of the symbolic coefficients are given in Plates 4, 5, 6, 7, and 8.

It is well now to review the process of calculation for determining the stresses in a building up to this point. First the values of w, P, F, X, Y, c, d, b, e, A and I must be calculated and tabulated for each story; also tabulate values of ΣF on the upper portion of the building for each story. Use the proper subscripts and exponents in designating these quantities. Now make blank computation schedules to conform with the blanks containing values of the symbolic coefficients as given in Plates 4, 5, 6, 7, and 8, only, under each coefficient, as a_n say, provide as many columns as there are stories in the structure, *i. e.*, as many as there are values of n. Start at the top of each column and, working downward, fill in each blank, making the calculations indicated in the corresponding blank of Plates 4, 5, 6, 7, and 8, with a Thacher slide rule or instrument

SYMBOLIC EQUATIONS

Values of C

$C^A_0 = 0$
$C^A_1 = a_0^{C-A} M^A_0 + i_0^{C-A} S^A_0$
$C^A_2 = a_1^{C-A} M^A_1 + i_1^{C-A} S^A_1 + C^A_1$
$C^A_3 = a_2^{C-A} M^A_2 + i_2^{C-A} S^A_2 + C^A_2$
$C^A_4 = a_3^{C-A} M^A_3 + i_3^{C-A} S^A_3 + C^A_3$

$C^B_0 = 0$
$C^B_1 = b_0^{C-B} M^B_0 + j_0^{C-B} S^B_0$
$C^B_2 = b_1^{C-B} M^B_1 + j_1^{C-B} S^B_1 + C^B_1$
$C^B_3 = b_2^{C-B} M^B_2 + j_2^{C-B} S^B_2 + C^B_2$
$C^B_4 = b_3^{C-B} M^B_3 + j_3^{C-B} S^B_3 + C^B_3$

$C^C_0 = 0$
$C^C_1 = c_0^{C-C} M^C_0 + k_0^{C-C} S^C_0$
$C^C_2 = c_1^{C-C} M^C_1 + k_1^{C-C} S^C_1 + C^C_1$
$C^C_3 = c_2^{C-C} M^C_2 + k_2^{C-C} S^C_2 + C^C_2$
$C^C_4 = c_3^{C-C} M^C_3 + k_3^{C-C} S^C_3 + C^C_3$

$C^D_0 = 0$
$C^D_1 = d_0^{C-D} M^D_0 + i_0^{C-D} S^A_0 + j_0^{C-D} S^B_0 + k_0^{C-D} S^C_0 + z_0^{C-D}$
$C^D_2 = d_1^{C-D} M^D_1 + i_1^{C-D} S^A_1 + j_1^{C-D} S^B_1 + k_1^{C-D} S^C_1 + z_1^{C-D} + C^D_1$
$C^D_3 = d_2^{C-D} M^D_2 + i_2^{C-D} S^A_2 + j_2^{C-D} S^B_2 + k_2^{C-D} S^C_2 + z_2^{C-D} + C^D_2$
$C^D_4 = d_3^{C-D} M^D_3 + i_3^{C-D} S^A_3 + j_3^{C-D} S^B_3 + k_3^{C-D} S^C_3 + z_3^{C-D} + C^D_3$

Values of δ

$\delta^A_0 = a_0^{\delta-A} M^A_0 + i_0^{\delta-A} S^A_0$
$\delta^A_1 = a_1^{\delta-A} M^A_1 + i_1^{\delta-A} S^A_1 + s_1^{\delta-A} C^A_1$
$\delta^A_2 = a_2^{\delta-A} M^A_2 + i_2^{\delta-A} S^A_2 + s_2^{\delta-A} C^A_2$
$\delta^A_3 = a_3^{\delta-A} M^A_3 + i_3^{\delta-A} S^A_3 + s_3^{\delta-A} C^A_3$

$\delta^B_0 = b_0^{\delta-B} M^B_0 + j_0^{\delta-B} S^B_0$
$\delta^B_1 = b_1^{\delta-B} M^B_1 + j_1^{\delta-B} S^B_1 + t_1^{\delta-B} C^B_1$
$\delta^B_2 = b_2^{\delta-B} M^B_2 + j_2^{\delta-B} S^B_2 + t_2^{\delta-B} C^B_2$
$\delta^B_3 = b_3^{\delta-B} M^B_3 + j_3^{\delta-B} S^B_3 + t_3^{\delta-B} C^B_3$

$\delta^C_0 = c_0^{\delta-C} M^C_0 + k_0^{\delta-C} S^C_0$
$\delta^C_1 = c_1^{\delta-C} M^C_1 + k_1^{\delta-C} S^C_1 + u_1^{\delta-C} C^C_1$
$\delta^C_2 = c_2^{\delta-C} M^C_2 + k_2^{\delta-C} S^C_2 + u_2^{\delta-C} C^C_2$
$\delta^C_3 = c_3^{\delta-C} M^C_3 + k_3^{\delta-C} S^C_3 + u_3^{\delta-C} C^C_3$

$\delta^D_0 = d_0^{\delta-D} M^D_0 + i_0^{\delta-D} S^A_0 + j_0^{\delta-D} S^B_0 + k_0^{\delta-D} S^C_0 + z_0^{\delta-D}$
$\delta^D_1 = d_1^{\delta-D} M^D_1 + i_1^{\delta-D} S^A_1 + j_1^{\delta-D} S^B_1 + k_1^{\delta-D} S^C_1 + z_1^{\delta-D} + v_1^{\delta-D} C^D_1$
$\delta^D_2 = d_2^{\delta-D} M^D_2 + i_2^{\delta-D} S^A_2 + j_2^{\delta-D} S^B_2 + k_2^{\delta-D} S^C_2 + z_2^{\delta-D} + v_2^{\delta-D} C^D_2$
$\delta^D_3 = d_3^{\delta-D} M^D_3 + i_3^{\delta-D} S^A_3 + j_3^{\delta-D} S^B_3 + k_3^{\delta-D} S^C_3 + z_3^{\delta-D} + v_3^{\delta-D} C^D_3$

Values of H.

$H^A_0 = l_0^{H-A} S^A_1 + i_0^{H-A} S^A_0 + z_0^{H-A}$
$H^A_1 = l_1^{H-A} S^A_2 + i_1^{H-A} S^A_1 + z_1^{H-A}$
$H^A_2 = l_2^{H-A} S^A_3 + i_2^{H-A} S^A_2 + z_2^{H-A}$
$H^A_3 = i_3^{H-A} S^A_3 + z_3^{H-A}$

$H^b_0 = l_0^{H-b} S^A_1 + m_0^{H-b} S^B_1 + i_0^{H-b} S^A_0 + j_0^{H-b} S^B_0 + z_0^{H-b}$
$H^b_1 = l_1^{H-b} S^A_2 + m_1^{H-b} S^B_2 + i_1^{H-b} S^A_1 + j_1^{H-b} S^B_1 + z_1^{H-b}$
$H^b_2 = l_2^{H-b} S^A_3 + m_2^{H-b} S^B_3 + i_2^{H-b} S^A_2 + j_2^{H-b} S^B_2 + z_2^{H-b}$
$H^b_3 = i_3^{H-b} S^A_3 + j_3^{H-b} S^B_3 + z_3^{H-b}$

$H^d_0 = l_0^{H-d} S^A_1 + m_0^{H-d} S^B_1 + n_0^{H-d} S^C_1 + i_0^{H-d} S^A_0 + j_0^{H-d} S^B_0 + k_0^{H-d} S^C_0 + z_0^{H-d}$
$H^d_1 = l_1^{H-d} S^A_2 + m_1^{H-d} S^B_2 + n_1^{H-d} S^C_2 + i_1^{H-d} S^A_1 + j_1^{H-d} S^B_1 + k_1^{H-d} S^C_1 + z_1^{H-d}$
$H^d_2 = l_2^{H-d} S^A_3 + m_2^{H-d} S^B_3 + n_2^{H-d} S^C_3 + i_2^{H-d} S^A_2 + j_2^{H-d} S^B_2 + k_2^{H-d} S^C_2 + z_2^{H-d}$
$H^d_3 = i_3^{H-d} S^A_3 + j_3^{H-d} S^B_3 + k_3^{H-d} S^C_3 + z_3^{H-d}$

Values of λ

$\lambda^a_0 = l_0^{\lambda-a} S^A_1 + i_0^{\lambda-a} S^A_0 + z_0^{\lambda-a}$
$\lambda^a_1 = l_1^{\lambda-a} S^A_2 + i_1^{\lambda-a} S^A_1 + z_1^{\lambda-a}$
$\lambda^a_2 = l_2^{\lambda-a} S^A_3 + i_2^{\lambda-a} S^A_2 + z_2^{\lambda-a}$
$\lambda^a_3 = i_3^{\lambda-a} S^A_3 + z_3^{\lambda-a}$

$\lambda^b_0 = l_0^{\lambda-b} S^A_1 + m_0^{\lambda-b} S^B_1 + i_0^{\lambda-b} S^A_0 + j_0^{\lambda-b} S^B_0 + z_0^{\lambda-b}$
$\lambda^b_1 = l_1^{\lambda-b} S^A_2 + m_1^{\lambda-b} S^B_2 + i_1^{\lambda-b} S^A_1 + j_1^{\lambda-b} S^B_1 + z_1^{\lambda-b}$
$\lambda^b_2 = l_2^{\lambda-b} S^A_3 + m_2^{\lambda-b} S^B_3 + i_2^{\lambda-b} S^A_2 + j_2^{\lambda-b} S^B_2 + z_2^{\lambda-b}$
$\lambda^b_3 = i_3^{\lambda-b} S^A_3 + j_3^{\lambda-b} S^B_3 + z_3^{\lambda-b}$

$\lambda^d_0 = l_0^{\lambda-d} S^A_1 + m_0^{\lambda-d} S^B_1 + n_0^{\lambda-d} S^C_1 + i_0^{\lambda-d} S^A_0 + j_0^{\lambda-d} S^B_0 + k_0^{\lambda-d} S^C_0 + z_0^{\lambda-d}$
$\lambda^d_1 = l_1^{\lambda-d} S^A_2 + m_1^{\lambda-d} S^B_2 + n_1^{\lambda-d} S^C_2 + i_1^{\lambda-d} S^A_1 + j_1^{\lambda-d} S^B_1 + k_1^{\lambda-d} S^C_1 + z_1^{\lambda-d}$
$\lambda^d_2 = l_2^{\lambda-d} S^A_3 + m_2^{\lambda-d} S^B_3 + n_2^{\lambda-d} S^C_3 + i_2^{\lambda-d} S^A_2 + j_2^{\lambda-d} S^B_2 + k_2^{\lambda-d} S^C_2 + z_2^{\lambda-d}$
$\lambda^d_3 = i_3^{\lambda-d} S^A_3 + j_3^{\lambda-d} S^B_3 + k_3^{\lambda-d} S^C_3 + z_3^{\lambda-d}$

Values of V

$V^A_0 = a_0^{V-A} M^A_0 + b_0^{V-A} M^B_0 + c_0^{V-A} M^C_0 + d_0^{V-A} M^D_0 + o_0^{V-A} V^B_0 + p_0^{V-A} V^C_0 + z_0^{V-A}$
$V^A_1 = a_1^{V-A} M^A_1 + b_1^{V-A} M^B_1 + c_1^{V-A} M^C_1 + d_1^{V-A} M^D_1 + o_1^{V-A} V^B_1 + p_1^{V-A} V^C_1 + z_1^{V-A}$
$V^A_2 = a_2^{V-A} M^A_2 + b_2^{V-A} M^B_2 + c_2^{V-A} M^C_2 + d_2^{V-A} M^D_2 + o_2^{V-A} V^B_2 + p_2^{V-A} V^C_2 + z_2^{V-A}$
$V^A_3 = a_3^{V-A} M^A_3 + b_3^{V-A} M^B_3 + c_3^{V-A} M^C_3 + d_3^{V-A} M^D_3 + o_3^{V-A} V^B_3 + p_3^{V-A} V^C_3 + z_3^{V-A}$

$V^D_0 = a_0^{V-D} M^A_0 + b_0^{V-D} M^B_0 + c_0^{V-D} M^C_0 + d_0^{V-D} M^D_0 + o_0^{V-D} V^B_0 + p_0^{V-D} V^C_0 + z_0^{V-D}$
$V^D_1 = a_1^{V-D} M^A_1 + b_1^{V-D} M^B_1 + c_1^{V-D} M^C_1 + d_1^{V-D} M^D_1 + o_1^{V-D} V^B_1 + p_1^{V-D} V^C_1 + z_1^{V-D}$
$V^D_2 = a_2^{V-D} M^A_2 + b_2^{V-D} M^B_2 + c_2^{V-D} M^C_2 + d_2^{V-D} M^D_2 + o_2^{V-D} V^B_2 + p_2^{V-D} V^C_2 + z_2^{V-D}$
$V^D_3 = a_3^{V-D} M^A_3 + b_3^{V-D} M^B_3 + c_3^{V-D} M^C_3 + d_3^{V-D} M^D_3 + o_3^{V-D} V^B_3 + p_3^{V-D} V^C_3 + z_3^{V-D}$

Values of α.

$\alpha^A_0 = a_0^{\alpha-A} M^A_0 + b_0^{\alpha-A} M^B_0 + c_0^{\alpha-A} M^C_0 + d_0^{\alpha-A} M^D_0 + o_0^{\alpha-A} V^B_0 + p_0^{\alpha-A} V^C_0 + z_0^{\alpha-A}$
$\alpha^A_1 = a_1^{\alpha-A} M^A_1 + b_1^{\alpha-A} M^B_1 + c_1^{\alpha-A} M^C_1 + d_1^{\alpha-A} M^D_1 + o_1^{\alpha-A} V^B_1 + p_1^{\alpha-A} V^C_1 + z_1^{\alpha-A}$
$\alpha^A_2 = a_2^{\alpha-A} M^A_2 + b_2^{\alpha-A} M^B_2 + c_2^{\alpha-A} M^C_2 + d_2^{\alpha-A} M^D_2 + o_2^{\alpha-A} V^B_2 + p_2^{\alpha-A} V^C_2 + z_2^{\alpha-A}$
$\alpha^A_3 = a_3^{\alpha-A} M^A_3 + b_3^{\alpha-A} M^B_3 + c_3^{\alpha-A} M^C_3 + d_3^{\alpha-A} M^D_3 + o_3^{\alpha-A} V^B_3 + p_3^{\alpha-A} V^C_3 + z_3^{\alpha-A}$

$\alpha^B_0 = o_0^{\alpha-B} V^B_0$
$\alpha^B_1 = o_1^{\alpha-B} V^B_1$
$\alpha^B_2 = o_2^{\alpha-B} V^B_2$
$\alpha^B_3 = o_3^{\alpha-B} V^B_3$

$\alpha^C_0 = p_0^{\alpha-C} V^C_0$
$\alpha^C_1 = p_1^{\alpha-C} V^C_1$
$\alpha^C_2 = p_2^{\alpha-C} V^C_2$
$\alpha^C_3 = p_3^{\alpha-C} V^C_3$

$\alpha^D_0 = a_0^{\alpha-D} M^A_0 + b_0^{\alpha-D} M^B_0 + c_0^{\alpha-D} M^C_0 + d_0^{\alpha-D} M^D_0 + o_0^{\alpha-D} V^B_0 + p_0^{\alpha-D} V^C_0 + z_0^{\alpha-D}$
$\alpha^D_1 = a_1^{\alpha-D} M^A_1 + b_1^{\alpha-D} M^B_1 + c_1^{\alpha-D} M^C_1 + d_1^{\alpha-D} M^D_1 + o_1^{\alpha-D} V^B_1 + p_1^{\alpha-D} V^C_1 + z_1^{\alpha-D}$
$\alpha^D_2 = a_2^{\alpha-D} M^A_2 + b_2^{\alpha-D} M^B_2 + c_2^{\alpha-D} M^C_2 + d_2^{\alpha-D} M^D_2 + o_2^{\alpha-D} V^B_2 + p_2^{\alpha-D} V^C_2 + z_2^{\alpha-D}$
$\alpha^D_3 = a_3^{\alpha-D} M^A_3 + b_3^{\alpha-D} M^B_3 + c_3^{\alpha-D} M^C_3 + d_3^{\alpha-D} M^D_3 + o_3^{\alpha-D} V^B_3 + p_3^{\alpha-D} V^C_3 + z_3^{\alpha-D}$

Values of Δ.

$\Delta^a_0 = a_0^{\Delta-a} M^A_0 + b_0^{\Delta-a} M^B_0 + c_0^{\Delta-a} M^C_0 + d_0^{\Delta-a} M^D_0 + o_0^{\Delta-a} V^B_0 + p_0^{\Delta-a} V^C_0 + z_0^{\Delta-a}$
$\Delta^a_1 = a_1^{\Delta-a} M^A_1 + b_1^{\Delta-a} M^B_1 + c_1^{\Delta-a} M^C_1 + d_1^{\Delta-a} M^D_1 + o_1^{\Delta-a} V^B_1 + p_1^{\Delta-a} V^C_1 + z_1^{\Delta-a} + \Delta^a_0$
$\Delta^a_2 = a_2^{\Delta-a} M^A_2 + b_2^{\Delta-a} M^B_2 + c_2^{\Delta-a} M^C_2 + d_2^{\Delta-a} M^D_2 + o_2^{\Delta-a} V^B_2 + p_2^{\Delta-a} V^C_2 + z_2^{\Delta-a} + \Delta^a_1$
$\Delta^a_3 = a_3^{\Delta-a} M^A_3 + b_3^{\Delta-a} M^B_3 + c_3^{\Delta-a} M^C_3 + d_3^{\Delta-a} M^D_3 + o_3^{\Delta-a} V^B_3 + p_3^{\Delta-a} V^C_3 + z_3^{\Delta-a} + \Delta^a_2$

$\Delta^b_0 = o_0^{\Delta-b} V^B_0 + p_0^{\Delta-b} V^C_0$
$\Delta^b_1 = o_1^{\Delta-b} V^B_1 + p_1^{\Delta-b} V^C_1 + \Delta^b_0$
$\Delta^b_2 = o_2^{\Delta-b} V^B_2 + p_2^{\Delta-b} V^C_2 + \Delta^b_1$
$\Delta^b_3 = o_3^{\Delta-b} V^B_3 + p_3^{\Delta-b} V^C_3 + \Delta^b_2$

$\Delta^d_0 = a_0^{\Delta-d} M^A_0 + b_0^{\Delta-d} M^B_0 + c_0^{\Delta-d} M^C_0 + d_0^{\Delta-d} M^D_0 + o_0^{\Delta-d} V^B_0 + p_0^{\Delta-d} V^C_0 + z_0^{\Delta-d}$
$\Delta^d_1 = a_1^{\Delta-d} M^A_1 + b_1^{\Delta-d} M^B_1 + c_1^{\Delta-d} M^C_1 + d_1^{\Delta-d} M^D_1 + o_1^{\Delta-d} V^B_1 + p_1^{\Delta-d} V^C_1 + z_1^{\Delta-d} + \Delta^d_0$
$\Delta^d_2 = a_2^{\Delta-d} M^A_2 + b_2^{\Delta-d} M^B_2 + c_2^{\Delta-d} M^C_2 + d_2^{\Delta-d} M^D_2 + o_2^{\Delta-d} V^B_2 + p_2^{\Delta-d} V^C_2 + z_2^{\Delta-d} + \Delta^d_1$
$\Delta^d_3 = a_3^{\Delta-d} M^A_3 + b_3^{\Delta-d} M^B_3 + c_3^{\Delta-d} M^C_3 + d_3^{\Delta-d} M^D_3 + o_3^{\Delta-d} V^B_3 + p_3^{\Delta-d} V^C_3 + z_3^{\Delta-d} + \Delta^d_2$

PLATE I.

Values of Q^a

$$Q_0^a = i_0^{Q-a}S_0^A + l_0^{Q-a}S_1^A + a_0^{Q-a}M_0^A + e_0^{Q-a}M_1^A + z_0^{Q-a}$$
$$Q_1^a = i_1^{Q-a}S_1^A + l_1^{Q-a}S_2^A + a_1^{Q-a}M_1^A + e_1^{Q-a}M_2^A + z_1^{Q-a}$$
$$Q_2^a = i_2^{Q-a}S_2^A + l_2^{Q-a}S_3^A + a_2^{Q-a}M_2^A + e_2^{Q-a}M_3^A + z_2^{Q-a}$$
$$Q_3^a = i_3^{Q-a}S_3^A + a_3^{Q-a}M_3^A + z_3^{Q-a}$$

Values of Q^b

$$Q_0^b = a_0^{Q-b}M_0^A + b_0^{Q-b}M_0^B + c_0^{Q-b}M_0^C + d_0^{Q-b}M_0^D + e_0^{Q-b}M_1^A + f_0^{Q-b}M_1^B + g_0^{Q-b}M_1^C + h_0^{Q-b}M_1^D + i_0^{Q-b}S_0^A + j_0^{Q-b}S_0^B + l_0^{Q-b}S_1^A + m_0^{Q-b}S_1^B + o_0^{Q-b}V_0^B + p_0^{Q-b}V_0^C + q_0^{Q-b}V_1^B + r_0^{Q-b}V_1^C + z_0^{Q-b}$$
$$Q_1^b = a_1^{Q-b}M_1^A + b_1^{Q-b}M_1^B + c_1^{Q-b}M_1^C + d_1^{Q-b}M_1^D + e_1^{Q-b}M_2^A + f_1^{Q-b}M_2^B + g_1^{Q-b}M_2^C + h_1^{Q-b}M_2^D + i_1^{Q-b}S_1^A + j_1^{Q-b}S_1^B + l_1^{Q-b}S_2^A + m_1^{Q-b}S_2^B + o_1^{Q-b}V_1^B + p_1^{Q-b}V_1^C + q_1^{Q-b}V_2^B + r_1^{Q-b}V_2^C + z_1^{Q-b}$$
$$Q_2^b = a_2^{Q-b}M_2^A + b_2^{Q-b}M_2^B + c_2^{Q-b}M_2^C + d_2^{Q-b}M_2^D + e_2^{Q-b}M_3^A + f_2^{Q-b}M_3^B + g_2^{Q-b}M_3^C + h_2^{Q-b}M_3^D + i_2^{Q-b}S_2^A + j_2^{Q-b}S_2^B + l_2^{Q-b}S_3^A + m_2^{Q-b}S_3^B + o_2^{Q-b}V_2^B + p_2^{Q-b}V_2^C + q_2^{Q-b}V_3^B + r_2^{Q-b}V_3^C + z_2^{Q-b}$$
$$Q_3^b = a_3^{Q-b}M_3^A + b_3^{Q-b}M_3^B + c_3^{Q-b}M_3^C + d_3^{Q-b}M_3^D + i_3^{Q-b}S_3^A + j_3^{Q-b}S_3^B + o_3^{Q-b}V_3^B + p_3^{Q-b}V_3^C + z_3^{Q-b}$$

Values of Q^d

$$Q_0^d = a_0^{Q-d}M_0^A + b_0^{Q-d}M_0^B + c_0^{Q-d}M_0^C + d_0^{Q-d}M_0^D + e_0^{Q-d}M_1^A + f_0^{Q-d}M_1^B + g_0^{Q-d}M_1^C + h_0^{Q-d}M_1^D + i_0^{Q-d}S_0^A + j_0^{Q-d}S_0^B + k_0^{Q-d}S_0^C + l_0^{Q-d}S_1^A + m_0^{Q-d}S_1^B + n_0^{Q-d}S_1^C + o_0^{Q-d}V_0^B + p_0^{Q-d}V_0^C + q_0^{Q-d}V_1^B + r_0^{Q-d}V_1^C + z_0^{Q-d}$$
$$Q_1^d = a_1^{Q-d}M_1^A + b_1^{Q-d}M_1^B + c_1^{Q-d}M_1^C + d_1^{Q-d}M_1^D + e_1^{Q-d}M_2^A + f_1^{Q-d}M_2^B + g_1^{Q-d}M_2^C + h_1^{Q-d}M_2^D + i_1^{Q-d}S_1^A + j_1^{Q-d}S_1^B + k_1^{Q-d}S_1^C + l_1^{Q-d}S_2^A + m_1^{Q-d}S_2^B + n_1^{Q-d}S_2^C + o_1^{Q-d}V_1^B + p_1^{Q-d}V_1^C + q_1^{Q-d}V_2^B + r_1^{Q-d}V_2^C + z_1^{Q-d}$$
$$Q_2^d = a_2^{Q-d}M_2^A + b_2^{Q-d}M_2^B + c_2^{Q-d}M_2^C + d_2^{Q-d}M_2^D + e_2^{Q-d}M_3^A + f_2^{Q-d}M_3^B + g_2^{Q-d}M_3^C + h_2^{Q-d}M_3^D + i_2^{Q-d}S_2^A + j_2^{Q-d}S_2^B + k_2^{Q-d}S_2^C + l_2^{Q-d}S_3^A + m_2^{Q-d}S_3^B + n_2^{Q-d}S_3^C + o_2^{Q-d}V_2^B + p_2^{Q-d}V_2^C + q_2^{Q-d}V_3^B + r_2^{Q-d}V_3^C + z_2^{Q-d}$$
$$Q_3^d = a_3^{Q-d}M_3^A + b_3^{Q-d}M_3^B + c_3^{Q-d}M_3^C + d_3^{Q-d}M_3^D + i_3^{Q-d}S_3^A + j_3^{Q-d}S_3^B + k_3^{Q-d}S_3^C + o_3^{Q-d}V_3^B + p_3^{Q-d}V_3^C + z_3^{Q-d}$$

Values of R^a

$$R_0^a = a_0^{R-a}M_0^A + b_0^{R-a}M_0^B + c_0^{R-a}M_0^C + d_0^{R-a}M_0^D + e_0^{R-a}M_1^A + f_0^{R-a}M_1^B + g_0^{R-a}M_1^C + h_0^{R-a}M_1^D + o_0^{R-a}V_0^B + p_0^{R-a}V_0^C + q_0^{R-a}V_1^B + r_0^{R-a}V_1^C + z_0^{R-a}$$
$$R_1^a = a_1^{R-a}M_1^A + b_1^{R-a}M_1^B + c_1^{R-a}M_1^C + d_1^{R-a}M_1^D + e_1^{R-a}M_2^A + f_1^{R-a}M_2^B + g_1^{R-a}M_2^C + h_1^{R-a}M_2^D + o_1^{R-a}V_1^B + p_1^{R-a}V_1^C + q_1^{R-a}V_2^B + r_1^{R-a}V_2^C + z_1^{R-a}$$
$$R_2^a = a_2^{R-a}M_2^A + b_2^{R-a}M_2^B + c_2^{R-a}M_2^C + d_2^{R-a}M_2^D + e_2^{R-a}M_3^A + f_2^{R-a}M_3^B + g_2^{R-a}M_3^C + h_2^{R-a}M_3^D + o_2^{R-a}V_2^B + p_2^{R-a}V_2^C + q_2^{R-a}V_3^B + r_2^{R-a}V_3^C + z_2^{R-a}$$
$$R_3^a = a_3^{R-a}M_3^A + b_3^{R-a}M_3^B + c_3^{R-a}M_3^C + d_3^{R-a}M_3^D + o_3^{R-a}V_3^B + p_3^{R-a}V_3^C + z_3^{R-a}$$

Values of R^b

$$R_0^b = a_0^{R-b}M_0^A + b_0^{R-b}M_0^B + c_0^{R-b}M_0^C + d_0^{R-b}M_0^D + e_0^{R-b}M_1^A + f_0^{R-b}M_1^B + g_0^{R-b}M_1^C + h_0^{R-b}M_1^D + o_0^{R-b}V_0^B + p_0^{R-b}V_0^C + q_0^{R-b}V_1^B + r_0^{R-b}V_1^C + z_0^{R-b}$$
$$R_1^b = a_1^{R-b}M_1^A + b_1^{R-b}M_1^B + c_1^{R-b}M_1^C + d_1^{R-b}M_1^D + e_1^{R-b}M_2^A + f_1^{R-b}M_2^B + g_1^{R-b}M_2^C + h_1^{R-b}M_2^D + o_1^{R-b}V_1^B + p_1^{R-b}V_1^C + q_1^{R-b}V_2^B + r_1^{R-b}V_2^C + z_1^{R-b}$$
$$R_2^b = a_2^{R-b}M_2^A + b_2^{R-b}M_2^B + c_2^{R-b}M_2^C + d_2^{R-b}M_2^D + e_2^{R-b}M_3^A + f_2^{R-b}M_3^B + g_2^{R-b}M_3^C + h_2^{R-b}M_3^D + o_2^{R-b}V_2^B + p_2^{R-b}V_2^C + q_2^{R-b}V_3^B + r_2^{R-b}V_3^C + z_2^{R-b}$$
$$R_3^b = a_3^{R-b}M_3^A + b_3^{R-b}M_3^B + c_3^{R-b}M_3^C + d_3^{R-b}M_3^D + o_3^{R-b}V_3^B + p_3^{R-b}V_3^C + z_3^{R-b}$$

Values of R^d

$$R_0^d = a_0^{R-d}M_0^A + b_0^{R-d}M_0^B + c_0^{R-d}M_0^C + d_0^{R-d}M_0^D + e_0^{R-d}M_1^A + f_0^{R-d}M_1^B + g_0^{R-d}M_1^C + h_0^{R-d}M_1^D + o_0^{R-d}V_0^B + p_0^{R-d}V_0^C + q_0^{R-d}V_1^B + r_0^{R-d}V_1^C + z_0^{R-d}$$
$$R_1^d = a_1^{R-d}M_1^A + b_1^{R-d}M_1^B + c_1^{R-d}M_1^C + d_1^{R-d}M_1^D + e_1^{R-d}M_2^A + f_1^{R-d}M_2^B + g_1^{R-d}M_2^C + h_1^{R-d}M_2^D + o_1^{R-d}V_1^B + p_1^{R-d}V_1^C + q_1^{R-d}V_2^B + r_1^{R-d}V_2^C + z_1^{R-d}$$
$$R_2^d = a_2^{R-d}M_2^A + b_2^{R-d}M_2^B + c_2^{R-d}M_2^C + d_2^{R-d}M_2^D + e_2^{R-d}M_3^A + f_2^{R-d}M_3^B + g_2^{R-d}M_3^C + h_2^{R-d}M_3^D + o_2^{R-d}V_2^B + p_2^{R-d}V_2^C + q_2^{R-d}V_3^B + r_2^{R-d}V_3^C + z_2^{R-d}$$
$$R_3^d = a_3^{R-d}M_3^A + b_3^{R-d}M_3^B + c_3^{R-d}M_3^C + d_3^{R-d}M_3^D + o_3^{R-d}V_3^B + p_3^{R-d}V_3^C + z_3^{R-d}$$

Equations A-a

$$a_0^{A-a}M_0^A + b_0^{A-a}M_0^B + i_0^{A-a}S_0^A + j_0^{A-a}S_0^B + l_0^{A-a}S_1^A + z_0^{A-a} = 0.$$
$$a_1^{A-a}M_1^A + b_1^{A-a}M_1^B + i_1^{A-a}S_1^A + j_1^{A-a}S_1^B + l_1^{A-a}S_2^A + z_1^{A-a} + s_1^{A-a}C_1^A + t_1^{A-a}C_1^B + P_1^{A-a}S_0^A = 0$$
$$a_2^{A-a}M_2^A + b_2^{A-a}M_2^B + i_2^{A-a}S_2^A + j_2^{A-a}S_2^B + l_2^{A-a}S_3^A + z_2^{A-a} + s_2^{A-a}C_2^A + t_2^{A-a}C_2^B + P_2^{A-a}S_1^A = 0$$
$$a_3^{A-a}M_3^A + b_3^{A-a}M_3^B + i_3^{A-a}S_3^A + j_3^{A-a}S_3^B + z_3^{A-a} + s_3^{A-a}C_3^A + t_3^{A-a}C_3^B + P_3^{A-a}S_2^A = 0$$

PLATE 2.

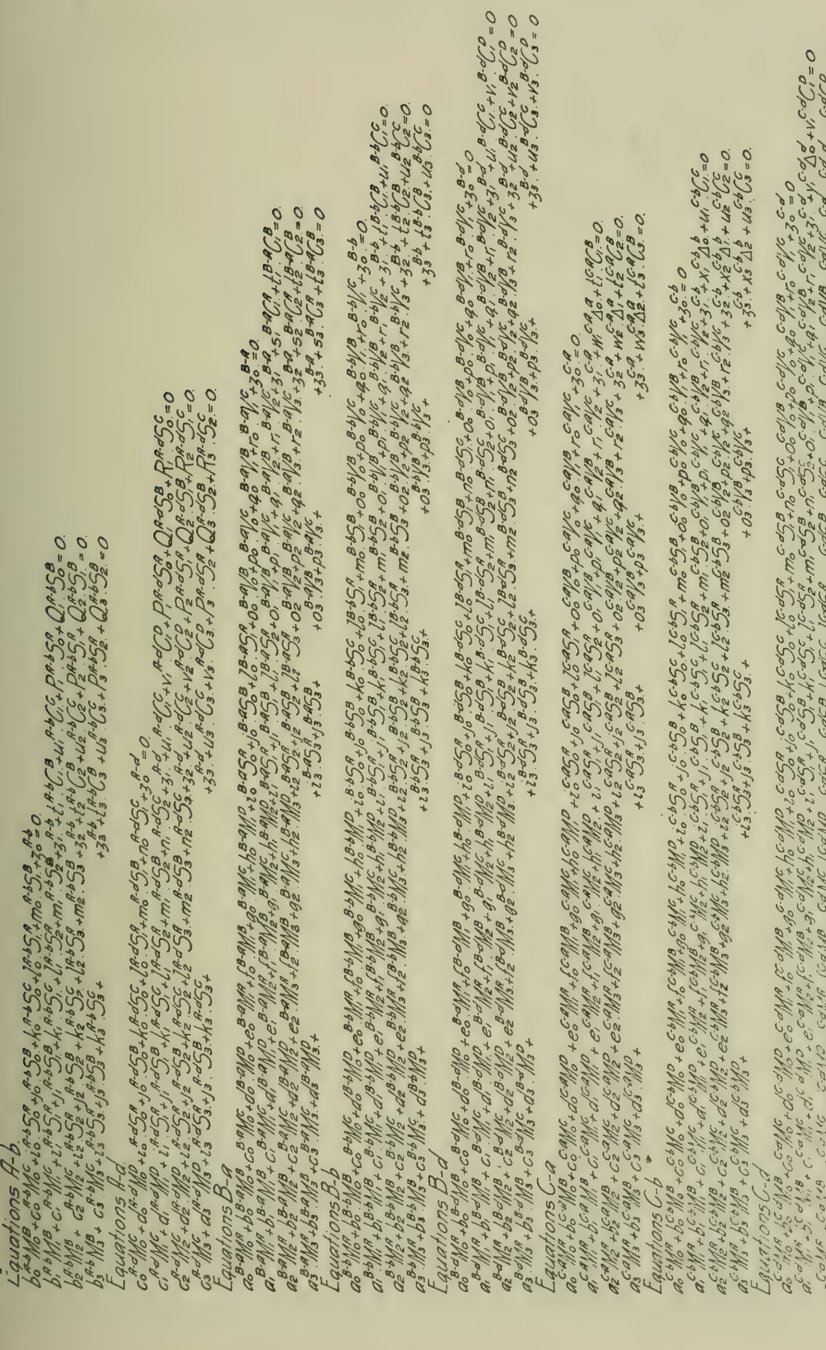

Equations A-b
Equations A-d
Equations B-a
Equations B-b
Equations B-d
Equations C-a
Equations C-b
Equations C-d

PLATE. 3

VALUES OF THE COEFFICIENTS IN THE SYMBOLIC EQUATIONS

	a_n	b_n	c_n	d_n
$C-A$	$c_n \div I_n^A$	0	0	0
$C-B$	0	$c_n \div I_n^B$	0	0
$C-C$	0	0	$c_n \div I_n^C$	0
$C-D$	0	0	0	$c_n \div I_n^D$
$\delta-A$	$c_n^2 \div 2I_n^A$	0	0	0
$\delta-B$	0	$c_n^2 \div 2I_n^B$	0	0
$\delta-C$	0	0	$c_n^2 \div 2I_n^C$	0
$\delta-D$	0	0	0	$c_n^2 \div 2I_n^D$
$H-a$	0	0	0	0
$H-b$	0	0	0	0
$H-d$	0	0	0	0
$\lambda-a$	0	0	0	0
$\lambda-b$	0	0	0	0
$\lambda-d$	0	0	0	0
$V-A$	$1 \div (b+b'+b'')$	$1 \div (b+b'+b'')$	$1 \div (b+b'+b'')$	$1 \div (b+b'+b'')$
$V-D$	$-1 \div (b+b'+b'')$	$-1 \div (b+b'+b'')$	$-1 \div (b+b'+b'')$	$-1 \div (b+b'+b'')$
$\alpha-A$	$(c_n+\frac{1}{2}d_{n-1}+\frac{1}{2}d_n)a_n^{V-A} \div A_n^A$	$(c_n+\frac{1}{2}d_{n-1}+\frac{1}{2}d_n)b_n^{V-A} \div A_n^A$	$(c_n+\frac{1}{2}d_{n-1}+\frac{1}{2}d_n)c_n^{V-A} \div A_n^A$	$(c_n+\frac{1}{2}d_{n-1}+\frac{1}{2}d_n)d_n^{V-A} \div A_n^A$
$\alpha-B$	0	0	0	0
$\alpha-C$	0	0	0	0
$\alpha-D$	$(c_n+\frac{1}{2}d_{n-1}+\frac{1}{2}d_n)a_n^{V-D} \div A_n^D$	$(c_n+\frac{1}{2}d_{n-1}+\frac{1}{2}d_n)b_n^{V-D} \div A_n^D$	$(c_n+\frac{1}{2}d_{n-1}+\frac{1}{2}d_n)c_n^{V-D} \div A_n^D$	$(c_n+\frac{1}{2}d_{n-1}+\frac{1}{2}d_n)d_n^{V-D} \div A_n^D$
$\Delta-a$	$-a_n^{\alpha-A}$	$-b_n^{\alpha-A}$	$-c_n^{\alpha-A}$	$-d_n^{\alpha-A}$
$\Delta-b$	0	0	0	0
$\Delta-d$	$a_n^{\alpha-D}$	$b_n^{\alpha-D}$	$c_n^{\alpha-D}$	$d_n^{\alpha-D}$
$Q-a$	$-1 \div I_n^a$	0	0	0
$Q-b$	$(-1+b\,a_n^{V-A}) \div I_n^b$	$(-1+b\,b_n^{V-A}) \div I_n^b$	$b\,c_n^{V-A} \div I_n^b$	$b\,d_n^{V-A} \div I_n^b$
$Q-d$	$[-1+(b+2b')a_n^{V-A}] \div I_n^d$	$[-1+(b+2b')b_n^{V-A}] \div I_n^d$	$[-1+(b+2b')c_n^{V-A}] \div I_n^d$	$(b+2b')d_n^{V-A} \div I_n^d$
$R-a$	$a_n^{V-A} \div I_n^a$	$b_n^{V-A} \div I_n^a$	$c_n^{V-A} \div I_n^a$	$d_n^{V-A} \div I_n^a$
$R-b$	$a_n^{V-A} \div I_n^b$	$b_n^{V-A} \div I_n^b$	$c_n^{V-} \div I_n^b$	$d_n^{V-A} \div I_n^b$
$R-d$	$a_n^{V-A} \div I_n^d$	$b_n^{V-A} \div I_n^d$	$c_n^{V-A} \div I_n^d$	$d_n^{V-A} \div I_n^d$
$A-a$	$a_n^{\delta-A}+\frac{1}{2}d_n a_n^{C-A}$	$-b_n^{\delta-B}-\frac{1}{2}d_n b_n^{C-B}$	0	0
$A-b$	0	$b_n^{\delta-B}+\frac{1}{2}d_n b_n^{C-B}$	$-c_n^{\delta-C}-\frac{1}{2}d_n c_n^{C-C}$	0
$A-d$	0	0	$c_n^{\delta-C}+\frac{1}{2}d_n c_n^{C-C}$	$-d_n^{\delta-D}-\frac{1}{2}d_n d_n^{C-D}$
$B-a$	$(a_n^{Q-a}+b\,a_n^{R-a})b-\frac{1}{2}b^2 a_n^{R-a}-a_n^{C-A}$	$\frac{1}{2}b^2 b_n^{R-a}+b_n^{C-B}$	$\frac{1}{2}b^2 c_n^{R-a}$	$\frac{1}{2}b^2 d_n^{R-a}$
$B-b$	$(a_n^{Q-b}+b'a_n^{R-b})b'-\frac{1}{2}b'^2 a_n^{R-b}$	$(b_n^{Q-b}+b'b_n^{R-b})b'-\frac{1}{2}b'^2 b_n^{R-b}-b_n^{C-B}$	$(c_n^{Q-b}+b'c_n^{R-b})b'-\frac{1}{2}b'^2 c_n^{R-b}+c_n^{C-C}$	$(d_n^{Q-b}+b'd_n^{R-b})b'-\frac{1}{2}b'^2 d_n^{R-b}$
$B-d$	$(a_n^{Q-d}+b''a_n^{R-d})b''-\frac{1}{2}b''^2 a_n^{R-d}$	$(b_n^{Q-d}+b''b_n^{R-d})b''-\frac{1}{2}b''^2 b_n^{R-d}$	$(c_n^{Q-d}+b''c_n^{R-d})b''-\frac{1}{2}b''^2 c_n^{R-d}-c_n^{C-C}$	$(d_n^{Q-d}+b''d_n^{R-d})b''-\frac{1}{2}b''^2 d_n^{R-d}+d_n^{C-D}$
$C-a$	$\frac{1}{2}(a_n^{Q-a}+b\,a_n^{R-a})b^2-\frac{1}{6}b^3 a_n^{R-a}-a_n^{\Delta-a}$	$\frac{1}{3}b^3 b_n^{R-a}-b_n^{\Delta-a}+b\,b_n^{C-B}$	$\frac{1}{3}b^3 c_n^{R-a}-c_n^{\Delta-a}$	$\frac{1}{3}b^3 d_n^{R-a}-d_n^{\Delta-a}$
$C-b$	$\frac{1}{2}(a_n^{Q-b}+b'a_n^{R-b})b'^2-\frac{1}{6}b'^3 a_n^{R-b}$	$\frac{1}{2}(b_n^{Q-b}+b'b_n^{R-b})b'^2-\frac{1}{6}b'^3 b_n^{R-b}$	$\frac{1}{2}(c_n^{Q-b}+b'c_n^{R-b})b'^2-\frac{1}{6}b'^3 c_n^{R-b}+b'c_n^{C-C}$	$\frac{1}{2}(d_n^{Q-b}+b'd_n^{R-b})b'^2-\frac{1}{6}b'^3 d_n^{R-b}$
$C-d$	$\frac{1}{2}(a_n^{Q-d}+b''a_n^{R-d})b''^2-\frac{1}{6}b''^3 a_n^{R-d}-a_n^{\Delta-d}$	$\frac{1}{2}(b_n^{Q-d}+b''b_n^{R-d})b''^2-\frac{1}{6}b''^3 b_n^{R-d}-b_n^{\Delta-d}$	$\frac{1}{2}(c_n^{Q-d}+b''c_n^{R-d})b''^2-\frac{1}{6}b''^3 c_n^{R-d}-c_n^{\Delta-d}$	$\frac{1}{2}(d_n^{Q-d}+b''d_n^{R-d})b''^2-\frac{1}{6}b''^3 d_n^{R-d}+b''d_n^{C-D}-d_n^{\Delta-d}$

PLATE 4.

VALUES OF THE COEFFICIENTS IN THE SYMBOLIC EQUATIONS.

	e_n	f_n	g_n	h_n	$\dot{i}_n$
C-A	0	0	0	0	$-c_n^2 \div 2I_n^A$
C-B	0	0	0	0	0
C-C	0	0	0	0	0
C-D	0	0	0	0	$c_n^2 \div 2I_n^D$
δ-A	0	0	0	0	$-c_n^3 \div 6I_n^A$
δ-B	0	0	0	0	0
δ-C	0	0	0	0	0
δ-D	0	0	0	0	$c_n^3 \div 6I_n^D$
H-a	0	0	0	0	-1
H-b	0	0	0	0	-1
H-d	0	0	0	0	-1
λ-a	0	0	0	0	$-b \div A_n^a$
λ-b	0	0	0	0	$-b' \div A_n^b$
λ-d	0	0	0	0	$-b'' \div A_n^d$
V-A	0	0	0	0	0
V-D	0	0	0	0	0
α-A	0	0	0	0	0
α-B	0	0	0	0	0
α-C	0	0	0	0	0
α-D	0	0	0	0	0
Δ-a	0	0	0	0	0
Δ-b	0	0	0	0	0
Δ-d	0	0	0	0	0
Q-a	$1 \div I_n^a$	0	0	0	$(c_n+\frac{1}{2}d_n)\div I_n^a$
Q-b	$(1-b\,a_{n+1}^{V-A})\div I_n^b$	$(1-b\,b_{n+1}^{V-A})\div I_n^b$	$-b\,c_{n+1}^{V-A}\div I_n^b$	$-b\,d_{n+1}^{V-A}\div I_n^b$	$(c_n+\frac{1}{2}d_n)\div I_n^b$
Q-d	$[1-(b+2b')a_{n+1}^{V-A}]\div I_n^d$	$[1-(b+2b')b_{n+1}^{V-A}]\div I_n^d$	$[1-(b+2b')c_{n+1}^{V-A}]\div I_n^d$	$-(b+2b')d_{n+1}^{V-A}\div I_n^d$	$(c_n+\frac{1}{2}d_n)\div I_n^d$
R-a	$-a_{n+1}^{V-A}\div I_n^a$	$-b_{n+1}^{V-A}\div I_n^a$	$-c_{n+1}^{V-A}\div I_n^a$	$-d_{n+1}^{V-A}\div I_n^a$	0
R-b	$-a_{n+1}^{V-A}\div I_n^b$	$-b_{n+1}^{V-A}\div I_n^b$	$-c_{n+1}^{V-A}\div I_n^b$	$-d_{n+1}^{V-A}\div I_n^b$	0
R-d	$-a_{n+1}^{V-A}\div I_n^d$	$-b_{n+1}^{V-A}\div I_n^d$	$-c_{n+1}^{V-A}\div I_n^d$	$-d_{n+1}^{V-A}\div I_n^d$	0
A-a	0	0	0	0	$\dot{i}_n^{\delta-A}+\frac{1}{2}d_n(\dot{i}_n^{C-A}-\dot{i}_n^{\lambda-a})+i_{n-1}^{\lambda-a}$
A-b	0	0	0	0	$-\dot{i}_n^{\lambda-b}+i_{n-1}^{\lambda-b}$
A-d	0	0	0	0	$-\dot{i}_n^{\delta-D}-\frac{1}{2}d_n(\dot{i}_n^{C-D}-\dot{i}_n^{\lambda-d})+i_{n-1}^{\lambda-d}$
B-a	$(e_n^{Q-a}+b\,e_n^{R-a})b-\frac{1}{2}b^2e_n^{R-a}$	$\frac{1}{2}b^2f_n^{R-a}$	$\frac{1}{2}b^2g_n^{R-a}$	$\frac{1}{2}b^2h_n^{R-a}$	$b\,\dot{i}_n^{Q-a}-\dot{i}_n^{C-A}$
B-b	$(e_n^{Q-b}+b'e_n^{R-b})b'-\frac{1}{2}b'^2e_n^{R-b}$	$(f_n^{Q-b}+b'f_n^{R-b})b'-\frac{1}{2}b'^2f_n^{R-b}$	$(g_n^{Q-b}+b'g_n^{R-b})b'-\frac{1}{2}b'^2g_n^{R-b}$	$(h_n^{Q-b}+b'h_n^{R-b})b'-\frac{1}{2}b'^2h_n^{R-b}$	$b'\dot{i}_n^{Q-b}$
B-d	$(e_n^{Q-d}+b''e_n^{R-d})b''-\frac{1}{2}b''^2e_n^{R-d}$	$(f_n^{Q-d}+b''f_n^{R-d})b''-\frac{1}{2}b''^2f_n^{R-d}$	$(g_n^{Q-d}+b''g_n^{R-d})b''-\frac{1}{2}b''^2g_n^{R-d}$	$(h_n^{Q-d}+b''h_n^{R-d})b''-\frac{1}{2}b''^2h_n^{R-d}$	$b''\dot{i}_n^{Q-d}+\dot{i}_n^{C-D}$
C-a	$\frac{1}{2}(e_n^{Q-a}+b\,e_n^{R-a})b^2-\frac{1}{6}b^3e_n^{R-a}$	$\frac{1}{3}b^3f_n^{R-a}$	$\frac{1}{3}b^3g_n^{R-a}$	$\frac{1}{3}b^3h_n^{R-a}$	$\frac{1}{2}b^2\dot{i}_n^{Q-a}$
C-b	$\frac{1}{2}(e_n^{Q-b}+b'e_n^{R-b})b'^2-\frac{1}{6}b'^3e_n^{R-b}$	$\frac{1}{2}(f_n^{Q-b}+b'f_n^{R-b})b'^2-\frac{1}{6}b'^3f_n^{R-b}$	$\frac{1}{2}(g_n^{Q-b}+b'g_n^{R-b})b'^2-\frac{1}{6}b'^3g_n^{R-b}$	$\frac{1}{2}(h_n^{Q-b}+b'h_n^{R-b})b'^2-\frac{1}{6}b'^3h_n^{R-b}$	$\frac{1}{2}b'^2\dot{i}_n^{Q-b}$
C-d	$\frac{1}{2}(e_n^{Q-d}+b''e_n^{R-d})b''^2-\frac{1}{6}b''^3e_n^{R-d}$	$\frac{1}{2}(f_n^{Q-d}+b''f_n^{R-d})b''^2-\frac{1}{6}b''^3f_n^{R-d}$	$\frac{1}{2}(g_n^{Q-d}+b''g_n^{R-d})b''^2-\frac{1}{6}b''^3g_n^{R-d}$	$\frac{1}{2}(h_n^{Q-d}+b''h_n^{R-d})b''^2-\frac{1}{6}b''^3h_n^{R-d}$	$\frac{1}{2}b''^2\dot{i}_n^{Q-d}+b''\dot{i}_n^{C-D}$

PLATE 5.

VALUES OF THE COEFFICIENTS IN THE SYMBOLIC EQUATIONS

	j_n	k_n	l_n	m_n	n_n	O_n
C-A	0	0	0	0	0	0
C-B	$-c_n^2\div 2I_n^B$	0	0	0	0	0
C-C	0	$-c_n^2\div 2I_n^C$	0	0	0	0
C-D	$c_n^2\div 2I_n^D$	$c_n^2\div 2I_n^D$	0	0	0	0
δ-A	0	0	0	0	0	0
δ-B	$-c_n^3\div 6I_n^B$	0	0	0	0	0
δ-C	0	$-c_n^3\div 6I_n^C$	0	0	0	0
δ-D	$c_n^3\div 6I_n^D$	$c_n^3\div 6I_n^D$	0	0	0	0
H-a	0	0	1	0	0	0
H-b	-1	0	1	1	0	0
H-d	-1	-1	1	1	1	0
λ-a	0	0	$b\div A_n^a$	0	0	0
λ-b	$-b'\div A_n^b$	0	$b'\div A_n^b$	$b'\div A_n^b$	0	0
λ-d	$-b''-A_n^d$	$-b''\div A_n^d$	$b''\div A_n^d$	$b''-A_n^d$	$b''\div A_n^d$	0
V-A	0	0	0	0	0	$-(b'+b'')\div(b+b'+b'')$
V-D	0	0	0	0	0	$-b\div(b+b'+b'')$
α-A	0	0	0	0	0	$(c_n+\frac{1}{2}d_{n-1}+\frac{1}{2}d_n)O_n^{V-A}\div A_n^A$
α-B	0	0	0	0	0	$(c_n+\frac{1}{2}d_{n-1}+\frac{1}{2}d_n)\div A_n^B$
α-C	0	0	0	0	0	0
α-D	0	0	0	0	0	$(c_n+\frac{1}{2}d_{n-1}+\frac{1}{2}d_n)O_n^{V-D}\div A_n^D$
Δ-a	0	0	0	0	0	$O_n^{\alpha-B}-O_n^{\alpha-A}$
Δ-b	0	0	0	0	0	$-O_n^{\alpha-B}$
Δ-d	0	0	0	0	0	$O_n^{\alpha-D}$
Q-a	0	0	$d_n\div 2I_n^a$	0	0	0
Q-b	$(c_n+\frac{1}{2}d_n)\div I_n^b$	0	$d_n\div 2I_n^b$	$d_n\div 2I_n^b$	0	$bO_n^{V-A}\div I_n^b$
Q-d	$(c_n+\frac{1}{2}d_n)-I_n^d$	$(c_n+\frac{1}{2}d_n)\div I_n^d$	$d_n-2I_n^d$	$d_n\div 2I_n^d$	$d_n\div 2I_n^d$	$[b'+(b+2b')O_n^{V-A}]\div I_n^d$
R-a	0	0	0	0	0	$O_n^{V-A}\div I_n^a$
R-b	0	0	0	0	0	$(1+O_n^{V-A})\div I_n^b$
R-d	0	0	0	0	0	$(1+O_n^{V-A})\div I_n^d$
A-a	$-j_n^{\delta-B}-\frac{1}{2}d_n j_n^{C-B}$	0	$-l_n^{\lambda-a}$	0	0	0
A-b	$j_n^{\delta-B}+\frac{1}{2}d_n j_n^{C-B}-j_n^{\lambda-b}+m_{n-1}^{\lambda-b}$	$-k_n^{\delta-C}-\frac{1}{2}d_n k_n^{C-C}$	$-l_n^{\lambda-b}$	$-m_n^{\lambda-b}$	0	0
A-d	$-j_n^{\delta-D}-\frac{1}{2}d_n j_n^{C-D}-j_n^{\lambda-d}+m_{n-1}^{\lambda-d}$	$k_n^{\delta-C}-k_n^{\delta-D}+\frac{1}{2}d_n(k_n^{C-C}-k_n^{C-D})-k_n^{\lambda-d}+n_{n-1}^{\lambda-d}$	$-l_n^{\lambda-d}$	$-m_n^{\lambda-d}$	$-n_n^{\lambda-d}$	0
B-a	j_n^{C-B}	0	bl_n^{Q-a}	0	0	$\frac{1}{2}b^2 O_n^{R-a}$
B-b	$b'j_n^{Q-b}-j_n^{C-B}$	k_n^{C-C}	$b'l_n^{Q-b}$	$b'm_n^{Q-b}$	0	$(O_n^{Q-b}+b'O_n^{R-b})b'-\frac{1}{2}b'^2 O_n^{R-b}$
B-d	$b''j_n^{Q-d}+j_n^{C-D}$	$b''k_n^{Q-d}+k_n^{C-D}-k_n^{C-C}$	$b''l_n^{Q-d}$	$b''m_n^{Q-d}$	$b''n_n^{Q-d}$	$(O_n^{Q-d}+b''O_n^{R-d})b''-\frac{1}{2}b''^2 O_n^{R-d}$
C-a	bj_n^{C-B}	0	$\frac{1}{2}b^2 l_n^{Q-a}$	0	0	$\frac{1}{3}b^3 O_n^{R-a}-O_n^{\Delta-a}$
C-b	$\frac{1}{2}b'^2 j_n^{Q-b}$	$b'k_n^{C-C}$	$\frac{1}{2}b'^2 l_n^{Q-b}$	$\frac{1}{2}b'^2 m_n^{Q-b}$	0	$\frac{1}{2}(O_n^{Q-b}+b'O_n^{R-b})b'^2-\frac{1}{6}b'^3 O_n^{R-b}-O_n^{\Delta-b}$
C-d	$\frac{1}{2}b'''^2 j_n^{Q-d}+b'''j_n^{C-D}$	$\frac{1}{2}b'''^2 k_n^{Q-d}+b'''k_n^{C-D}$	$\frac{1}{2}b'''^2 l_n^{Q-d}$	$\frac{1}{2}b'''^2 m_n^{Q-d}$	$\frac{1}{2}b'''^2 n_n^{Q-d}$	$\frac{1}{2}(O_n^{Q-d}+b'''O_n^{R-d})b'''^2-\frac{1}{6}b'''^3 O_n^{R-d}-O_n^{\Delta-d}$

PLATE 6.

VALUES OF THE COEFFICIENTS IN THE SYMBOLIC EQUATIONS.

	p_n	q_n	r_n	s_n	t_n
C-A	0	0	0	1	0
C-B	0	0	0	0	1
C-C	0	0	0	0	0
C-D	0	0	0	0	0
δ-A	0	0	0	c_n	0
δ-B	0	0	0	0	c_n
δ-C	0	0	0	0	0
δ-D	0	0	0	0	0
H-a	0	0	0	0	0
H-b	0	0	0	0	0
H-d	0	0	0	0	0
λ-a	0	0	0	0	0
λ-b	0	0	0	0	0
λ-d	0	0	0	0	0
V-A	$-b''\div(b+b'+b'')$	0	0	0	0
V-D	$-(b+b')\div(b+b'+b'')$	0	0	0	0
α-A	$(c_n+\frac{1}{2}d_{n-1}+\frac{1}{2}d_n)p_n^{V-A}\div A_n^A$	0	0	0	0
α-B	0	0	0	0	0
α-C	$(c_n+\frac{1}{2}d_{n-1}+\frac{1}{2}d_n)\div A_n^C$	0	0	0	0
α-D	$(c_n+\frac{1}{2}d_{n-1}+\frac{1}{2}d_n).p_n^{V-D}\div A_n^D$	0	0	0	0
Δ-a	$-p_n^{\alpha-A}$	0	0	0	0
Δ-b	$p_n^{\alpha-C}$	0	0	0	0
Δ-d	$p_n^{\alpha-D}-p_n^{\alpha-C}$	0	0	0	0
Q-a	0	0	0	0	0
Q-b	$b.p_n^{V-A}\div I_n^b$	$-b.o_{n+1}^{V-A}\div I_n^b$	$-b.p_{n+1}^{V-A}\div I_n^b$	0	0
Q-d	$(b+2b').p_n^{V-A}\div I_n^d$	$[-b'-(b+2b').o_{n+1}^{V-A}]\div I_n^d$	$-(b+2b')p_{n+1}^{V-A}\div I_n^d$	0	0
R-a	$p_n^{V-A}\div I_n^a$	$-o_{n+1}^{V-A}\div I_n^a$	$-p_{n+1}^{V-A}\div I_n^a$	0	0
R-b	$p_n^{V-A}\div I_n^b$	$(-1-o_{n+1}^{V-A})\div I_n^b$	$-p_{n+1}^{V-A}\div I_n^b$	0	0
R-d	$(1+p_n^{V-A})\div I_n^d$	$(-1-o_{n+1}^{V-A})\div I_n^d$	$(-1-p_{n+1}^{V-A})\div I_n^d$	0	0
A-a	0	0	0	$s_n^{\delta-A}+\frac{1}{2}d_n.s_n^{C-A}+\frac{1}{2}d_{n-1}$	$-t_n^{\delta-B}-\frac{1}{2}d_n t_n^{C-B}-\frac{1}{2}d_{n-1}$
A-b	0	0	0	0	$t_n^{\delta-B}+\frac{1}{2}d_n.t_n^{C-B}+\frac{1}{2}d_{n-1}$
A-d	0	0	0	0	0
B-a	$\frac{1}{2}b^2 p_n^{R-a}$	$\frac{1}{2}b^2.q_n^{R-a}$	$\frac{1}{2}b^2 r_n^{R-a}$	$-s_n^{C-A}$	t_n^{C-B}
B-b	$(p_n^{Q-b}+b'.p_n^{R-b})b'-\frac{1}{2}b'^2 p_n^{R-b}$	$(q_n^{Q-b}+b'q_n^{R-b})b'-\frac{1}{2}b'^2 q_n^{R-b}$	$(r_n^{Q-b}+b'r_n^{R-b})b'-\frac{1}{2}b'^2 r_n^{R-b}$	0	$-t_n^{C-B}$
B-d	$(p_n^{Q-d}+b''p_n^{R-d})b''-\frac{1}{2}b''^2 p_n^{R-d}$	$(q_n^{Q-d}+b''q_n^{R-d})b''-\frac{1}{2}b''^2 q_n^{R-d}$	$(r_n^{Q-d}+b''r_n^{R-d})b''-\frac{1}{2}b''^2 r_n^{R-d}$	0	0
C-a	$\frac{1}{3}b^3 p_n^{R-a}-p_n^{\Delta-a}$	$\frac{1}{3}b^3 q_n^{R-a}$	$\frac{1}{3}b^3 r_n^{R-a}$	0	$b t_n^{C-B}$
C-b	$\frac{1}{2}(p_n^{Q-b}+b'p_n^{R-b})b'^2-\frac{1}{6}b'^3 p_n^{R-b}-p_n^{\Delta-b}$	$\frac{1}{2}(q_n^{Q-b}+b'q_n^{R-b})b'^2-\frac{1}{6}b'^3 q_n^{R-b}$	$\frac{1}{2}(r_n^{Q-b}+b'r_n^{R-b})b'^2-\frac{1}{6}b'^3 r_n^{R-b}$	0	0
C-d	$\frac{1}{2}(p_n^{Q-d}+b''p_n^{R-d})b''^2-\frac{1}{6}b''^3 p_n^{R-d}-p_n^{\Delta-d}$	$\frac{1}{2}(q_n^{Q-d}+b''q_n^{R-d})b''^2-\frac{1}{6}b''^3 q_n^{R-d}$	$\frac{1}{2}(r_n^{Q-d}+b''r_n^{R-d})b''^2-\frac{1}{6}b''^3 r_n^{R-d}$	0	0

PLATE 7.

VALUES OF THE COEFFICIENTS IN THE SYMBOLIC EQUATIONS.

	U_n	V_n	W_n	X_n	Y_n	P_n	Q_n	R_n	Z_n
C-A	0	0	0	0	0	0	0	0	0
C-B	0	0	0	0	0	0	0	0	0
C-C	1	0	0	0	0	0	0	0	0
C-D	0	1	0	0	0	0	0	0	$-c_n^2\Sigma F_n \div 2I_n^D$
δ-A	0	0	0	0	0	0	0	0	0
δ-B	0	0	0	0	0	0	0	0	0
δ-C	c_n	0	0	0	0	0	0	0	0
δ-D	0	c_n	0	0	0	0	0	0	$-c_n^3\Sigma F_n \div 6I_n^D$
H-a	0	0	0	0	0	0	0	0	F_n^A
H-b	0	0	0	0	0	0	0	0	F_n^A
H-d	0	0	0	0	0	0	0	0	F_n^A
λ-a	0	0	0	0	0	0	0	0	$b.Z_n^{H-a} \div A_n^a$
λ-b	0	0	0	0	0	0	0	0	$b'.Z_n^{H-b} \div A_n^b$
λ-d	0	0	0	0	0	0	0	0	$b''.Z_n^{H-d} \div A_n^d$
V-A	0	0	0	0	0	0	0	0	$-X_n \div (b+b'+b'')$
V-D	0	0	0	0	0	0	0	0	$Y_n + X_n \div (b+b'+b'')$
α-A	0	0	0	0	0	0	0	0	$(c_n+\frac{1}{2}d_{n-1}+\frac{1}{2}d_n).Z_n^{V-A} \div A_n^A$
α-B	0	0	0	0	0	0	0	0	0
α-C	0	0	0	0	0	0	0	0	0
α-D	0	0	0	0	0	0	0	0	$(c_n+\frac{1}{2}d_{n-1}+\frac{1}{2}d_n)Z_n^{V-D} \div A_n^D$
Δ-a	0	0	1	0	0	0	0	0	$-Z_n^{\alpha-A}$
Δ-b	0	0	0	1	0	0	0	0	0
Δ-d	0	0	0	0	1	0	0	0	$Z_n^{\alpha-D}$
Q-a	0	0	0	0	0	0	0	0	$-P_n^A e_n^A \div I_n^a$
Q-b	0	0	0	0	0	0	0	0	$[-P_n^A(b+e_n^A)-\frac{1}{2}b^2W_n+b(Z_n^{V-A}-Z_{n+1}^{V-A})] \div I_n^b$
Q-d	0	0	0	0	0	0	0	0	$[-P_n^A(b+b'+e_n^A)-\frac{1}{2}(b+b')^2W_n+(b+2b')(Z_n^{V-A}-Z_{n+1}^{V-A})] \div I_n^d$
R-a	0	0	0	0	0	0	0	0	$[Z_n^{V-A}-Z_{n+1}^{V-A}-P_n^A] \div I_n^a$
R-b	0	0	0	0	0	0	0	0	$[Z_n^{V-A}-Z_{n+1}^{V-A}-P_n^A-bW_n] \div I_n^b$
R-d	0	0	0	0	0	0	0	0	$[Z_n^{V-A}-Z_{n+1}^{V-A}-P_n^A-(b+b')W_n] \div I_n^d$
A-a	0	0	0	0	0	$-b \div A_{n-1}^a$	0	0	$-Z_n^{\lambda-a}+Z_{n-1}^{\lambda-a}$
A-b	$-U_n^{\delta-C}-\frac{1}{2}d_nU_n^{C-C}-\frac{1}{2}d_{n-1}$	0	0	0	0	$-b' \div A_{n-1}^b$	$-b' \div A_{n-1}^b$	0	$-Z_n^{\lambda-b}+Z_{n-1}^{\lambda-b}$
A-d	$U_n^{\delta-C}+\frac{1}{2}d_nU_n^{C-C}+\frac{1}{2}d_{n-1}$	$-V_n^{\delta-D}-\frac{1}{2}d_nV_n^{C-D}-\frac{1}{2}d_{n-1}$	0	0	0	$-b'' \div A_{n-1}^d$	$-b'' \div A_{n-1}^d$	$-b'' \div A_{n-1}^d$	$-Z_n^{\delta-D}-\frac{1}{2}d_nZ_n^{C-D}-Z_n^{\lambda-d}+Z_{n-1}^{\lambda-d}$
B-a	0	0	0	0	0	0	0	0	$(Z_n^{Q-a}+bZ_n^{R-a})b-\frac{1}{2}b^2Z_n^{R-a}-b^3W_n-6I_n^a$
B-b	U_n^{C-C}	0	0	0	0	0	0	0	$(Z_n^{Q-b}+b'Z_n^{R-b})b'-\frac{1}{2}b'^2Z_n^{R-b}-b'^3W_n \div 6I_n^b$
B-d	$-U_n^{C-C}$	V_n^{C-D}	0	0	0	0	0	0	$(Z_n^{Q-d}+b''Z_n^{R-d})b''-\frac{1}{2}b''^2Z_n^{R-d}-b''^3W_n \div 6I_n^d+Z_n^{C-D}$
C-a	0	0	−1	0	0	0	0	0	$(Z_n^{Q-a}+bZ_n^{R-a})\frac{1}{2}b^2-\frac{1}{6}b^3Z_n^{R-a}-b^4W_n \div 8I_n^a-Z_n^{\Delta-a}$
C-b	$b'U_n^{C-C}$	0	0	−1	0	0	0	0	$(Z_n^{Q-b}+b'Z_n^{R-b})\frac{1}{2}b'^2-\frac{1}{6}b'^3Z_n^{R-b}-b'^4W_n \div 8I_n^b$
C-d	0	$b''.V_n^{C-D}$	0	0	−1	0	0	0	$(Z_n^{Q-d}+b''Z_n^{R-d})\frac{1}{2}b''^2-\frac{1}{6}b''^3Z_n^{R-d}-b''^4W_n \div 8I_n^d-Z_n^{\Delta-d}+bZ_n^{C-D}$

PLATE 8.

of at least equal precision. All calculations should be most carefully checked by an independent calculator. It will be noticed, as the calculations for any column of the table are made, that quantities once computed are referred to in succeeding calculations, *e. g.*, in finding the value of a_n^{A-a} the coefficient of M_n^A in equation A_n^a, the quantities $a_n^{\delta-a}$ and a_n^{C-A} already computed, are here used. These calculations will be found to be quite simple and are not laborious.

Solution of the Equations of Unknowns.—As has been previously mentioned, the unknowns of the 0 or basement story must first be expressed in terms of those of the first story; then those of the first story in terms of those of the second story, and so on for each story until the top story is reached and its solution gives values in arithmetical units, there being no unknowns above the top story.

Now referring to the nine symbolic equations of the 0 story, A_0^a, A_0^b, A_0^d, B_0^a, B_0^b, B_0^d, C_0^a, C_0^b, and C_0^d it will be seen that each equation contains more or less of the nine unknowns of both the 0 and first stories. Let these nine equations be now written as shown in the first nine equations of Plate 9. The coefficients are here represented by the Greek letters with a subscript which refers to the *number of the equation* in which the coefficient occurs, these equations being numbered from 1 to 9. The quantity ω is used to represent the numerical constant together with all the first story unknowns of the equations; this makes the solution much more easily understood, since ω is then treated as though it were a numerical constant itself. Now the solution of these nine simplified equations is essentially the same as the elimination method used by Gauss in the solution of normal equations in the adjustment of observations. The method is given and, it is thought, explains itself, in Plates 9 and 10. The original equations are marked "1," thus A–a–1, and in the successive steps of the solution the new forms of the equations are distinguished by numbers corresponding to the number of eliminations made; thus B–a–4 represents equation B–a–1 from which M_0^A, M_0^B and M_0^C have been eliminated. In the actual solution of the nine equations it is not necessary to write out these successive steps, but merely to make a table in which the *coefficients* in all the equations of Plates 9 and 10 may be

Let the nine equations be written with simpler coefficients as follows:-

A-a-1 $\alpha_1 M_o^A + \beta_1 M_o^B + \gamma_1 M_o^C + \delta_1 M_o^D + \theta_1 S_o^A + \phi_1 S_o^B + \psi_1 S_o^C + \epsilon_1 V_o^B + \lambda_1 V_o^C + \omega_1 = 0.$

A-b-1 $\alpha_2 M_o^A + \beta_2 M_o^B + \gamma_2 M_o^C + \delta_2 M_o^D + \theta_2 S_o^A + \phi_2 S_o^B + \psi_2 S_o^C + \epsilon_2 V_o^B + \lambda_2 V_o^C + \omega_2 = 0$

A-d-1 $\alpha_3 M_o^A + \beta_3 M_o^B + \gamma_3 M_o^C + \delta_3 M_o^D + \theta_3 S_o^A + \phi_3 S_o^B + \psi_3 S_o^C + \epsilon_3 V_o^B + \lambda_3 V_o^C + \omega_3 = 0$

B-a-1 $\alpha_4 M_o^A + \beta_4 M_o^B + \gamma_4 M_o^C + \delta_4 M_o^D + \theta_4 S_o^A + \phi_4 S_o^B + \psi_4 S_o^C + \epsilon_4 V_o^B + \lambda_4 V_o^C + \omega_4 = 0.$

B-b-1 $\alpha_5 M_o^A + \beta_5 M_o^B + \gamma_5 M_o^C + \delta_5 M_o^D + \theta_5 S_o^A + \phi_5 S_o^B + \psi_5 S_o^C + \epsilon_5 V_o^B + \lambda_5 V_o^C + \omega_5 = 0.$

B-d-1 $\alpha_6 M_o^A + \beta_6 M_o^B + \gamma_6 M_o^C + \delta_6 M_o^D + \theta_6 S_o^A + \phi_6 S_o^B + \psi_6 S_o^C + \epsilon_6 V_o^B + \lambda_6 V_o^C + \omega_6 = 0.$

C-a-1 $\alpha_7 M_o^A + \beta_7 M_o^B + \gamma_7 M_o^C + \delta_7 M_o^D + \theta_7 S_o^A + \phi_7 S_o^B + \psi_7 S_o^C + \epsilon_7 V_o^B + \lambda_7 V_o^C + \omega_7 = 0.$

C-b-1 $\alpha_8 M_o^A + \beta_8 M_o^B + \gamma_8 M_o^C + \delta_8 M_o^D + \theta_8 S_o^A + \phi_8 S_o^B + \psi_8 S_o^C + \epsilon_8 V_o^B + \lambda_8 V_o^C + \omega_8 = 0.$

C-d-1 $\alpha_9 M_o^A + \beta_9 M_o^B + \gamma_9 M_o^C + \delta_9 M_o^D + \theta_9 S_o^A + \phi_9 S_o^B + \psi_9 S_o^C + \epsilon_9 V_o^B + \lambda_9 V_o^C + \omega_9 = 0.$

From Equation A-a-1

$$M_o^A = \beta_1' M_o^B + \gamma_1' M_o^C + \delta_1' M_o^D + \theta_1' S_o^A + \phi_1' S_o^B + \psi_1' S_o^C + \epsilon_1' V_o^B + \lambda_1' V_o^C + \omega_1'$$

Substituting this value of M_o^A in the succeeding equations gives

A-b-2 $\beta_2' M_o^B + \gamma_2' M_o^C + \delta_2' M_o^D + \theta_2' S_o^A + \phi_2' S_o^B + \psi_2' S_o^C + \epsilon_2' V_o^B + \lambda_2' V_o^C + \omega_2' = 0.$

A-d-2 $\beta_3' M_o^B + \gamma_3' M_o^C + \delta_3' M_o^D + \theta_3' S_o^A + \phi_3' S_o^B + \psi_3' S_o^C + \epsilon_3' V_o^B + \lambda_3' V_o^C + \omega_3' = 0.$

B-a-2 $\beta_4' M_o^B + \gamma_4' M_o^C + \delta_4' M_o^D + \theta_4' S_o^A + \phi_4' S_o^B + \psi_4' S_o^C + \epsilon_4' V_o^B + \lambda_4' V_o^C + \omega_4' = 0.$

B-b-2 $\beta_5' M_o^B + \gamma_5' M_o^C + \delta_5' M_o^D + \theta_5' S_o^A + \phi_5' S_o^B + \psi_5' S_o^C + \epsilon_5' V_o^B + \lambda_5' V_o^C + \omega_5' = 0$

B-d-2 $\beta_6' M_o^B + \gamma_6' M_o^C + \delta_6' M_o^D + \theta_6' S_o^A + \phi_6' S_o^B + \psi_6' S_o^C + \epsilon_6' V_o^B + \lambda_6' V_o^C + \omega_6' = 0.$

C-a-2 $\beta_7' M_o^B + \gamma_7' M_o^C + \delta_7' M_o^D + \theta_7' S_o^A + \phi_7' S_o^B + \psi_7' S_o^C + \epsilon_7' V_o^B + \lambda_7' V_o^C + \omega_7' = 0.$

C-b-2 $\beta_8' M_o^B + \gamma_8' M_o^C + \delta_8' M_o^D + \theta_8' S_o^A + \phi_8' S_o^B + \psi_8' S_o^C + \epsilon_8' V_o^B + \lambda_8' V_o^C + \omega_8' = 0.$

C-d-2 $\beta_9' M_o^B + \gamma_9' M_o^C + \delta_9' M_o^D + \theta_9' S_o^A + \phi_9' S_o^B + \psi_9' S_o^C + \epsilon_9' V_o^B + \lambda_9' V_o^C + \omega_9' = 0.$

From Equation A-b-2

$$M_o^B = \gamma_2'' M_o^C + \delta_2'' M_o^D + \theta_2'' S_o^A + \phi_2'' S_o^B + \psi_2'' S_o^C + \epsilon_2'' V_o^B + \lambda_2'' V_o^C + \omega_2''$$

Substituting this value of M_o^B in the succeeding equations gives

A-d-3 $\gamma_3'' M_o^C + \delta_3'' M_o^D + \theta_3'' S_o^A + \phi_3'' S_o^B + \psi_3'' S_o^C + \epsilon_3'' V_o^B + \lambda_3'' V_o^C + \omega_3'' = 0.$

B-a-3 $\gamma_4'' M_o^C + \delta_4'' M_o^D + \theta_4'' S_o^A + \phi_4'' S_o^B + \psi_4'' S_o^C + \epsilon_4'' V_o^B + \lambda_4'' V_o^C + \omega_4'' = 0.$

B-b-3 $\gamma_5'' M_o^C + \delta_5'' M_o^D + \theta_5'' S_o^A + \phi_5'' S_o^B + \psi_5'' S_o^C + \epsilon_5'' V_o^B + \lambda_5'' V_o^C + \omega_5'' = 0.$

B-d-3 $\gamma_6'' M_o^C + \delta_6'' M_o^D + \theta_6'' S_o^A + \phi_6'' S_o^B + \psi_6'' S_o^C + \epsilon_6'' V_o^B + \lambda_6'' V_o^C + \omega_6'' = 0.$

C-a-3 $\gamma_7'' M_o^C + \delta_7'' M_o^D + \theta_7'' S_o^A + \phi_7'' S_o^B + \psi_7'' S_o^C + \epsilon_7'' V_o^B + \lambda_7'' V_o^C + \omega_7'' = 0.$

C-b-3 $\gamma_8'' M_o^C + \delta_8'' M_o^D + \theta_8'' S_o^A + \phi_8'' S_o^B + \psi_8'' S_o^C + \epsilon_8'' V_o^B + \lambda_8'' V_o^C + \omega_8'' = 0.$

C-d-3 $\gamma_9'' M_o^C + \delta_9'' M_o^D + \theta_9'' S_o^A + \phi_9'' S_o^B + \psi_9'' S_o^C + \epsilon_9'' V_o^B + \lambda_9'' V_o^C + \omega_9'' = 0.$

From Equation A-d-3

$$M_o^C = \delta_3''' M_o^D + \theta_3''' S_o^A + \phi_3''' S_o^B + \psi_3''' S_o^C + \epsilon_3''' V_o^B + \lambda_3''' V_o^C + \omega_3'''.$$

Substituting this value of M_o^C in the succeeding equations gives

B-a-4 $\delta_4''' M_o^D + \theta_4''' S_o^A + \phi_4''' S_o^B + \psi_4''' S_o^C + \epsilon_4''' V_o^B + \lambda_4''' V_o^C + \omega_4''' = 0.$

B-b-4 $\delta_5''' M_o^D + \theta_5''' S_o^A + \phi_5''' S_o^B + \psi_5''' S_o^C + \epsilon_5''' V_o^B + \lambda_5''' V_o^C + \omega_5''' = 0.$

B-d-4 $\delta_6''' M_o^D + \theta_6''' S_o^A + \phi_6''' S_o^B + \psi_6''' S_o^C + \epsilon_6''' V_o^B + \lambda_6''' V_o^C + \omega_6''' = 0.$

C-a-4 $\delta_7''' M_o^D + \theta_7''' S_o^A + \phi_7''' S_o^B + \psi_7''' S_o^C + \epsilon_7''' V_o^B + \lambda_7''' V_o^C + \omega_7''' = 0.$

C-b-4 $\delta_8''' M_o^D + \theta_8''' S_o^A + \phi_8''' S_o^B + \psi_8''' S_o^C + \epsilon_8''' V_o^B + \lambda_8''' V_o^C + \omega_8''' = 0.$

C-d-4 $\delta_9''' M_o^D + \theta_9''' S_o^A + \phi_9''' S_o^B + \psi_9''' S_o^C + \epsilon_9''' V_o^B + \lambda_9''' V_o^C + \omega_9''' = 0.$

PLATE 9.

From Equation B-a-4

$$M_0^D = \theta_4^{IV} S_0^A + \phi_4^{IV} S_0^B + \psi_4^{IV} S_0^C + \varepsilon_4^{IV} V_0^B + \lambda_4^{IV} V_0^C + \omega_4^{IV}.$$

Substituting this value of M_0^D in the succeeding equations gives

$$\begin{array}{ll} B\text{-}b\text{-}5 & \theta_5^{IV} S_0^A + \phi_5^{IV} S_0^B + \psi_5^{IV} S_0^C + \varepsilon_5^{IV} V_0^B + \lambda_5^{IV} V_0^C + \omega_5^{IV} = 0 \\ B\text{-}d\text{-}5 & \theta_6^{IV} S_0^A + \phi_6^{IV} S_0^B + \psi_6^{IV} S_0^C + \varepsilon_6^{IV} V_0^B + \lambda_6^{IV} V_0^C + \omega_6^{IV} = 0. \\ C\text{-}a\text{-}5 & \theta_7^{IV} S_0^A + \phi_7^{IV} S_0^B + \psi_7^{IV} S_0^C + \varepsilon_7^{IV} V_0^B + \lambda_7^{IV} V_0^C + \omega_7^{IV} = 0. \\ C\text{-}b\text{-}5 & \theta_8^{IV} S_0^A + \phi_8^{IV} S_0^B + \psi_8^{IV} S_0^C + \varepsilon_8^{IV} V_0^B + \lambda_8^{IV} V_0^C + \omega_8^{IV} = 0 \\ C\text{-}d\text{-}5 & \theta_9^{IV} S_0^A + \phi_9^{IV} S_0^B + \psi_9^{IV} S_0^C + \varepsilon_9^{IV} V_0^B + \lambda_9^{IV} V_0^C + \omega_9^{IV} = 0 \end{array}$$

From Equation B-b-5

$$S_0^A = \phi_5^{V} S_0^B + \psi_5^{V} S_0^C + \varepsilon_5^{V} V_0^B + \lambda_5^{V} V_0^C + \omega_5^{V}$$

Substituting this value of S_0^A in the succeeding equations gives

$$\begin{array}{ll} B\text{-}d\text{-}6 & \phi_6^{V} S_0^B + \psi_6^{V} S_0^C + \varepsilon_6^{V} V_0^B + \lambda_6^{V} V_0^C + \omega_6^{V} = 0. \\ C\text{-}a\text{-}6 & \phi_7^{V} S_0^B + \psi_7^{V} S_0^C + \varepsilon_7^{V} V_0^B + \lambda_7^{V} V_0^C + \omega_7^{V} = 0 \\ C\text{-}b\text{-}6 & \phi_8^{V} S_0^B + \psi_8^{V} S_0^C + \varepsilon_8^{V} V_0^B + \lambda_8^{V} V_0^C + \omega_8^{V} = 0. \\ C\text{-}d\text{-}6 & \phi_9^{V} S_0^B + \psi_9^{V} S_0^C + \varepsilon_9^{V} V_0^B + \lambda_9^{V} V_0^C + \omega_9^{V} = 0 \end{array}$$

From Equation B-d-6

$$S_0^B = \psi_6^{VI} S_0^C + \varepsilon_6^{VI} V_0^B + \lambda_6^{VI} V_0^C + \omega_6^{VI}$$

Substituting this value of S_0^B in the succeeding equations gives

$$\begin{array}{ll} C\text{-}a\text{-}7 & \psi_7^{VI} S_0^C + \varepsilon_7^{VI} V_0^B + \lambda_7^{VI} V_0^C + \omega_7^{VI} = 0. \\ C\text{-}b\text{-}7 & \psi_8^{VI} S_0^C + \varepsilon_8^{VI} V_0^B + \lambda_8^{VI} V_0^C + \omega_8^{VI} = 0. \\ C\text{-}d\text{-}7 & \psi_9^{VI} S_0^C + \varepsilon_9^{VI} V_0^B + \lambda_9^{VI} V_0^C + \omega_9^{VI} = 0. \end{array}$$

From Equation C-a-7

$$S_0^C = \varepsilon_7^{VII} V_0^B + \lambda_7^{VII} V_0^C + \omega_7^{VII}.$$

Substituting this value of S_0^C in the succeeding equations gives

$$\begin{array}{ll} C\text{-}b\text{-}8 & \varepsilon_8^{VII} V_0^B + \lambda_8^{VII} V_0^C + \omega_8^{VII} = 0 \\ C\text{-}d\text{-}8 & \varepsilon_9^{VII} V_0^B + \lambda_9^{VII} V_0^C + \omega_9^{VII} = 0 \end{array}$$

From Equation C-b-8

$$V_0^B = \lambda_8^{VIII} V_0^C + \omega_8^{VIII}$$

Substituting this value of V_0^B in the succeeding equation gives

$$\lambda_9^{VIII} V_0^C + \omega_9^{VIII} = 0$$

$$\text{or} \quad V_0^C = \omega_9^{IX}.$$

PLATE 10.

TABULATED VALUES OF THE COEFFICIENTS IN THE SOLUTION OF THE EQUATIONS FOR THE O STORY.

Equation	α	β	γ	δ	θ	ϕ	ψ	ε	λ
A-a-1	a_o^{A-a}	b_o^{A-a}	0	0	i_o^{A-a}	j_o^{A-a}	0	0	0
A-b-1	0	b_o^{A-b}	c_o^{A-b}	0	i_o^{A-b}	j_o^{A-b}	k_o^{A-b}	0	0
A-d-1	0	0	c_o^{A-d}	d_o^{A-d}	i_o^{A-d}	j_o^{A-d}	k_o^{A-d}	0	0
B-a-1	a_o^{B-a}	b_o^{B-a}	c_o^{B-a}	d_o^{B-a}	i_o^{B-a}	j_o^{B-a}	0	o_o^{B-a}	p_o^{B-a}
B-b-1	a_o^{B-b}	b_o^{B-b}	c_o^{B-b}	d_o^{B-b}	i_o^{B-b}	j_o^{B-b}	k_o^{B-b}	o_o^{B-b}	p_o^{B-b}
B-d-1	a_o^{B-d}	b_o^{B-d}	c_o^{B-d}	d_o^{B-d}	i_o^{B-d}	j_o^{B-d}	k_o^{B-d}	o_o^{B-d}	p_o^{B-d}
C-a-1	a_o^{C-a}	b_o^{C-a}	c_o^{C-a}	d_o^{C-a}	i_o^{C-a}	j_o^{C-a}	0	o_o^{C-a}	p_o^{C-a}
C-b-1	a_o^{C-b}	b_o^{C-b}	c_o^{C-b}	d_o^{C-b}	i_o^{C-b}	j_o^{C-b}	k_o^{C-b}	o_o^{C-b}	p_o^{C-b}
C-d-1	a_o^{C-d}	b_o^{C-d}	c_o^{C-d}	d_o^{C-d}	i_o^{C-d}	j_o^{C-d}	k_o^{C-d}	o_o^{C-d}	p_o^{C-d}
	$M_o^A=$	$-\beta_1\div\alpha_1$	$-\gamma_1\div\alpha_1$	$-\delta_1\div\alpha_1$	$-\theta_1-\alpha_1$	$-\phi_1-\alpha_1$	$-\psi_1\div\alpha_1$	$-\varepsilon_1\div\alpha_1$	$-\lambda_1\div\alpha_1$
	A-b-2	$\beta_2+\alpha_2.\beta_1'$	$\gamma_2+\alpha_2\gamma_1'$	$\delta_2+\alpha_2.\delta_1'$	$\theta_2+\alpha_2.\theta_1'$	$\phi_2+\alpha_2.\phi_1'$	$\psi_2+\alpha_2\psi_1'$	$\varepsilon_2+\alpha_2.\varepsilon_1'$	$\lambda_2+\alpha_2\lambda_1'$
	A-d-2	$\beta_3+\alpha_3.\beta_1'$	$\gamma_3+\alpha_3\gamma_1'$	$\delta_3+\alpha_3.\delta_1'$	$\theta_3+\alpha_3.\theta_1'$	$\phi_3+\alpha_3.\phi_1'$	$\psi_3+\alpha_3.\psi_1'$	$\varepsilon_3+\alpha_3.\varepsilon_1'$	$\lambda_3+\alpha_3.\lambda_1'$
	B-a-2	$\beta_4+\alpha_4\beta_1'$	$\gamma_4+\alpha_4.\gamma_1'$	$\delta_4+\alpha_4\delta_1'$	$\theta_4+\alpha_4.\theta_1'$	$\phi_4+\alpha_4.\phi_1'$	$\psi_4+\alpha_4.\psi_1'$	$\varepsilon_4+\alpha_4.\varepsilon_1'$	$\lambda_4+\alpha_4.\lambda_1'$
	B-b-2	$\beta_5+\alpha_5.\beta_1'$	$\gamma_5+\alpha_5.\gamma_1'$	$\delta_5+\alpha_5.\delta_1'$	$\theta_5+\alpha_5.\theta_1'$	$\phi_5+\alpha_5.\phi_1'$	$\psi_5+\alpha_5\psi_1'$	$\varepsilon_5+\alpha_5.\varepsilon_1'$	$\lambda_5+\alpha_5.\lambda_1'$
	B-d-2	$\beta_6+\alpha_6\beta_1'$	$\gamma_6+\alpha_6.\gamma_1'$	$\delta_6+\alpha_6\delta_1'$	$\theta_6+\alpha_6.\theta_1'$	$\phi_6+\alpha_6\phi_1'$	$\psi_6+\alpha_6.\psi_1'$	$\varepsilon_6+\alpha_6.\varepsilon_1'$	$\lambda_6+\alpha_6.\lambda_1'$
	C-a-2	$\beta_7+\alpha_7\beta_1'$	$\gamma_7+\alpha_7\gamma_1'$	$\delta_7+\alpha_7\delta_1'$	$\theta_7+\alpha_7.\theta_1'$	$\phi_7+\alpha_7\phi_1'$	$\psi_7+\alpha_7.\psi_1'$	$\varepsilon_7+\alpha_7.\varepsilon_1'$	$\lambda_7+\alpha_7\lambda_1'$
	C-b-2	$\beta_8+\alpha_8\beta_1'$	$\gamma_8+\alpha_8.\gamma_1'$	$\delta_8+\alpha_8\delta_1'$	$\theta_8+\alpha_8\theta_1'$	$\phi_8+\alpha_8.\phi_1'$	$\psi_8+\alpha_8\psi_1'$	$\varepsilon_8+\alpha_8.\varepsilon_1'$	$\lambda_8+\alpha_8\lambda_1'$
	C-d-2	$\beta_9+\alpha_9\beta_1'$	$\gamma_9+\alpha_9\gamma_1'$	$\delta_9+\alpha_9.\delta_1'$	$\theta_9+\alpha_9.\theta_1'$	$\phi_9+\alpha_9\phi_1'$	$\psi_9+\alpha_9.\psi_1'$	$\varepsilon_9+\alpha_9.\varepsilon_1'$	$\lambda_9+\alpha_9.\lambda_1'$
		$M_o^B=$	$-\gamma_2'\div\beta_2'$	$-\delta_2'\div\beta_2'$	$-\theta_2'\div\beta_2'$	$-\phi_2'\div\beta_2'$	$-\psi_2'\div\beta_2'$	$-\varepsilon_2'\div\beta_2'$	$-\lambda_2'\div\beta_2'$
		A-d-3	$\gamma_3'+\beta_3'.\gamma_2''$	$\delta_3'+\beta_3'\delta_2''$	$\theta_3'+\beta_3'\theta_2''$	$\phi_3'+\beta_3'.\phi_2''$	$\psi_3'+\beta_3'.\psi_2''$	$\varepsilon_3'+\beta_3'.\varepsilon_2''$	$\lambda_3'+\beta_3'\lambda_2''$
		B-a-3	$\gamma_4'+\beta_4'.\gamma_2''$	$\delta_4'+\beta_4'.\delta_2''$	$\theta_4'+\beta_4'.\theta_2''$	$\phi_4'+\beta_4'.\phi_2''$	$\psi_4'+\beta_4'\psi_2''$	$\varepsilon_4'+\beta_4'.\varepsilon_2''$	$\lambda_4'+\beta_4'\lambda_2''$
		B-b-3	$\gamma_5'+\beta_5'\gamma_2''$	$\delta_5'+\beta_5'.\delta_2''$	$\theta_5'+\beta_5'.\theta_2''$	$\phi_5'+\beta_5'.\phi_2''$	$\psi_5'+\beta_5'.\psi_2''$	$\varepsilon_5'+\beta_5'.\varepsilon_2''$	$\lambda_5'+\beta_5'.\lambda_2''$
		B-d-3	$\gamma_6'+\beta_6'\gamma_2''$	$\delta_6'+\beta_6'.\delta_2''$	$\theta_6'+\beta_6'.\theta_2''$	$\phi_6'+\beta_6'.\phi_2''$	$\psi_6'+\beta_6'.\psi_2''$	$\varepsilon_6'+\beta_6'\varepsilon_2''$	$\lambda_6'+\beta_6'.\lambda_2''$
		C-a-3	$\gamma_7'+\beta_7'.\gamma_2''$	$\delta_7'+\beta_7'.\delta_2''$	$\theta_7'+\beta_7'.\theta_2''$	$\phi_7'+\beta_7'.\phi_2''$	$\psi_7'+\beta_7'.\psi_2''$	$\varepsilon_7'+\beta_7'.\varepsilon_2''$	$\lambda_7'+\beta_7'\lambda_2''$
		C-b-3	$\gamma_8'+\beta_8'\gamma_2''$	$\delta_8'+\beta_8'.\delta_2''$	$\theta_8'+\beta_8'.\theta_2''$	$\phi_8'+\beta_8'.\phi_2''$	$\psi_8'+\beta_8'.\psi_2''$	$\varepsilon_8'+\beta_8'.\varepsilon_2''$	$\lambda_8'+\beta_8'.\lambda_2''$
		C-d-3	$\gamma_9'+\beta_9'.\gamma_2''$	$\delta_9'+\beta_9'\delta_2''$	$\theta_9'+\beta_9'.\theta_2''$	$\phi_9'+\beta_9'.\phi_2''$	$\psi_9'+\beta_9'.\psi_2''$	$\varepsilon_9'+\beta_9'.\varepsilon_2''$	$\lambda_9'+\beta_9'.\lambda_2''$
			$M_o^C=$	$-\delta_3''\div\gamma_3''$	$-\theta_3''\div\gamma_3''$	$-\phi_3''\div\gamma_3''$	$-\psi_3''-\gamma_3''$	$-\varepsilon_3''-\gamma_3''$	$-\lambda_3''\div\gamma_3''$
			B-a-4	$\delta_4''+\gamma_4''.\delta_3'''$	$\theta_4''+\gamma_4''.\theta_3'''$	$\phi_4''+\gamma_4''.\phi_3'''$	$\psi_4''+\gamma_4''.\psi_3'''$	$\varepsilon_4''+\gamma_4''.\varepsilon_3'''$	$\lambda_4''+\gamma_4''.\lambda_3'''$
			B-b-4	$\delta_5''+\gamma_5''.\delta_3'''$	$\theta_5''+\gamma_5''.\theta_3'''$	$\phi_5''+\gamma_5''.\phi_3'''$	$\psi_5''+\gamma_5''.\psi_3'''$	$\varepsilon_5''+\gamma_5''.\varepsilon_3'''$	$\lambda_5''+\gamma_5''.\lambda_3'''$
			B-d-4	$\delta_6''+\gamma_6''.\delta_3'''$	$\theta_6''+\gamma_6''.\theta_3'''$	$\phi_6''+\gamma_6''.\phi_3'''$	$\psi_6''+\gamma_6''\psi_3'''$	$\varepsilon_6''+\gamma_6''.\varepsilon_3'''$	$\lambda_6''+\gamma_6''.\lambda_3'''$
			C-a-4	$\delta_7''+\gamma_7''.\delta_3'''$	$\theta_7''+\gamma_7''.\theta_3'''$	$\phi_7''+\gamma_7''.\phi_3'''$	$\psi_7''+\gamma_7''\psi_3'''$	$\varepsilon_7''+\gamma_7''.\varepsilon_3'''$	$\lambda_7''+\gamma_7''.\lambda_3'''$
			C-b-4	$\delta_8''+\gamma_8''.\delta_3'''$	$\theta_8''+\gamma_8''\theta_3'''$	$\phi_8''+\gamma_8''.\phi_3'''$	$\psi_8''+\gamma_8''\psi_3'''$	$\varepsilon_8''+\gamma_8''.\varepsilon_3'''$	$\lambda_8''+\gamma_8''\lambda_3'''$
			C-d-4	$\delta_9''+\gamma_9''.\delta_3'''$	$\theta_9''+\gamma_9''.\theta_3'''$	$\phi_9''+\gamma_9''.\phi_3'''$	$\psi_9''+\gamma_9''.\psi_3'''$	$\varepsilon_9''+\gamma_9''.\varepsilon_3'''$	$\lambda_9''+\gamma_9''\lambda_3'''$
				$M_o^D=$	$-\theta_4'''\div\delta_4'''$	$-\phi_4'''\div\delta_4'''$	$-\psi_4'''-\delta_4'''$	$-\varepsilon_4'''\div\delta_4'''$	$-\lambda_4'''\div\delta_4'''$
				B-b-5	$\theta_5'''+\delta_5'''\theta_4^{IV}$	$\phi_5'''+\delta_5'''.\phi_4^{IV}$	$\psi_5'''+\delta_5'''.\psi_4^{IV}$	$\varepsilon_5'''+\delta_5'''.\varepsilon_4^{IV}$	$\lambda_5'''+\delta_5'''.\lambda_4^{IV}$
				B-d-5	$\theta_6'''+\delta_6'''.\theta_4^{IV}$	$\phi_6'''+\delta_6'''.\phi_4^{IV}$	$\psi_6'''+\delta_6'''.\psi_4^{IV}$	$\varepsilon_6'''+\delta_6'''\varepsilon_4^{IV}$	$\lambda_6'''+\delta_6'''\lambda_4^{IV}$
				C-a-5	$\theta_7'''+\delta_7'''.\theta_4^{IV}$	$\phi_7'''+\delta_7'''.\phi_4^{IV}$	$\psi_7'''+\delta_7'''\psi_4^{IV}$	$\varepsilon_7'''+\delta_7'''.\varepsilon_4^{IV}$	$\lambda_7'''+\delta_7'''.\lambda_4^{IV}$
				C-b-5	$\theta_8'''+\delta_8'''.\theta_4^{IV}$	$\phi_8'''+\delta_8'''.\phi_4^{IV}$	$\psi_8'''+\delta_8'''.\psi_4^{IV}$	$\varepsilon_8'''+\delta_8'''.\varepsilon_4^{IV}$	$\lambda_8'''+\delta_8'''.\lambda_4^{IV}$
				C-d-5	$\theta_9'''+\delta_9'''.\theta_4^{IV}$	$\phi_9'''+\delta_9'''.\phi_4^{IV}$	$\psi_9'''+\delta_9'''.\psi_4^{IV}$	$\varepsilon_9'''+\delta_9'''.\varepsilon_4^{IV}$	$\lambda_9'''+\delta_9'''.\lambda_4^{IV}$
					$S_o^A=$	$-\phi_5^{IV}\div\theta_5^{IV}$	$-\psi_5^{IV}\div\theta_5^{IV}$	$-\varepsilon_5^{IV}\div\theta_5^{IV}$	$-\lambda_5^{IV}-\theta_5^{IV}$
					B-d-6	$\phi_6^{IV}+\theta_6^{IV}\phi_5^{V}$	$\psi_6^{IV}+\theta_6^{IV}\psi_5^{V}$	$\varepsilon_6^{IV}+\theta_6^{IV}.\varepsilon_5^{V}$	$\lambda_6^{IV}+\theta_6^{IV}.\lambda_5^{V}$
					C-a-6	$\phi_7^{IV}+\theta_7^{IV}\phi_5^{V}$	$\psi_7^{IV}+\theta_7^{IV}.\psi_5^{V}$	$\varepsilon_7^{IV}+\theta_7^{IV}.\varepsilon_5^{V}$	$\lambda_7^{IV}+\theta_7^{IV}\lambda_5^{V}$
					C-b-6	$\phi_8^{IV}+\theta_8^{IV}.\phi_5^{V}$	$\psi_8^{IV}+\theta_8^{IV}.\psi_5^{V}$	$\varepsilon_8^{IV}+\theta_8^{IV}.\varepsilon_5^{V}$	$\lambda_8^{IV}+\theta_8^{IV}\lambda_5^{V}$
					C-d-6	$\phi_9^{IV}+\theta_9^{IV}.\phi_5^{V}$	$\psi_9^{IV}+\theta_9^{IV}\psi_5^{V}$	$\varepsilon_9^{IV}+\theta_9^{IV}.\varepsilon_5^{V}$	$\lambda_9^{IV}+\theta_9^{IV}\lambda_5^{V}$
						$S_o^B=$	$-\psi_6^{V}\div\phi_6^{V}$	$-\varepsilon_6^{V}\div\phi_6^{V}$	$-\lambda_6^{V}\div\phi_6^{V}$
						C-a-7	$\psi_7^{V}+\phi_7^{V}.\psi_6^{VI}$	$\varepsilon_7^{V}+\phi_7^{V}.\varepsilon_6^{VI}$	$\lambda_7^{V}+\phi_7^{V}\lambda_6^{VI}$
						C-b-7	$\psi_8^{V}+\phi_8^{V}.\psi_6^{VI}$	$\varepsilon_8^{V}+\phi_8^{V}.\varepsilon_6^{VI}$	$\lambda_8^{V}+\phi_8^{V}\lambda_6^{VI}$
						C-d-7	$\psi_9^{V}+\phi_9^{V}\psi_6^{VI}$	$\varepsilon_9^{V}+\phi_9^{V}.\varepsilon_6^{VI}$	$\lambda_9^{V}+\phi_9^{V}\lambda_6^{VI}$
							$S_o^C=$	$-\varepsilon_7^{VI}-\psi_7^{VI}$	$-\lambda_7^{VI}-\psi_7^{VI}$
							C-b-8	$\varepsilon_8^{VI}+\psi_8^{VI}.\varepsilon_7^{VII}$	$\lambda_8^{VI}+\psi_8^{VI}\lambda_7^{VII}$
							C-d-8	$\varepsilon_9^{VI}+\psi_9^{VI}.\varepsilon_7^{VII}$	$\lambda_9^{VI}+\psi_9^{VI}.\lambda_7^{VII}$
								$V_o^B=$	$-\lambda_8^{VII}\div\varepsilon_8^{VII}$
								C-d-9	$\lambda_9^{VII}\div\varepsilon_9^{VII}.\lambda_8^{VIII}$
									$V_o^C=$

Note:—This table corresponds to the solution equations given on the preceding pages

PLATE II.

TABULATED VALUES OF THE COEFFICIENTS OF THE TERMS INVOLVED IN THE EXPRESSIONS ω

e	f	g	h	l	m	n	q	r	z
0	0	0	0	l_0^{A-a}	0	0	0	0	z_0^{A-a}
0	0	0	0	l_0^{A-b}	m_0^{A-b}	0	0	0	z_0^{A-b}
0	0	0	0	l_0^{A-d}	m_0^{A-d}	n_0^{A-d}	0	0	z_0^{A-d}
e_0^{B-a}	f_0^{B-a}	g_0^{B-a}	h_0^{B-a}	l_0^{B-a}	0	0	q_0^{B-a}	r_0^{B-a}	z_0^{B-a}
e_0^{B-b}	f_0^{B-b}	g_0^{B-b}	h_0^{B-b}	l_0^{B-b}	m_0^{B-b}	0	q_0^{B-b}	r_0^{B-b}	z_0^{B-b}
e_0^{B-d}	f_0^{B-d}	g_0^{B-d}	h_0^{B-d}	l_0^{B-d}	m_0^{B-d}	n_0^{B-d}	q_0^{B-d}	r_0^{B-d}	z_0^{B-d}
e_0^{C-a}	f_0^{C-a}	g_0^{C-a}	h_0^{C-a}	l_0^{C-a}	0	0	q_0^{C-a}	r_0^{C-a}	z_0^{C-a}
e_0^{C-b}	f_0^{C-b}	g_0^{C-b}	h_0^{C-b}	l_0^{C-b}	m_0^{C-b}	0	q_0^{C-b}	r_0^{C-b}	z_0^{C-b}
e_0^{C-d}	f_0^{C-d}	g_0^{C-d}	h_0^{C-d}	l_0^{C-d}	m_0^{C-d}	n_0^{C-d}	q_0^{C-d}	r_0^{C-d}	z_0^{C-d}
$-e_1\div\alpha_1$	$-f_1\div\alpha_1$	$-g_1\div\alpha_1$	$-h_1\div\alpha_1$	$-l_1\div\alpha_1$	$-m_1\div\alpha$	$-n_1\div\alpha_1$	$-q_1\div\alpha_1$	$-r_1\div\alpha_1$	$-z_1\div\alpha_1$
$e_2+\alpha_2.e'_1$	$f_2+\alpha_2 f'_1$	$g_2+\alpha_2.g'_1$	$h_2+\alpha_2.h'_1$	$l_2+\alpha_2.l'_1$	$m_2+\alpha_2.m'_1$	$n_2+\alpha_2.n'_1$	$q_2+\alpha_2.q'_1$	$r_2+\alpha_2.r'_1$	$z_2+\alpha_2.z'_1$
$e_3+\alpha_3.e'_1$	$f_3+\alpha_3.f'_1$	$g_3+\alpha_3.g'_1$	$h_3+\alpha_3.h'_1$	$l_3+\alpha_3.l'_1$	$m_3+\alpha_3.m'_1$	$n_3+\alpha_3.n'_1$	$q_3+\alpha_3.q'_1$	$r_3+\alpha_3.r'_1$	$z_3+\alpha_3.z'_1$
$e_4+\alpha_4.e'_1$	$f_4+\alpha_4.f'_1$	$g_4+\alpha_4.g'_1$	$h_4+\alpha_4.h'_1$	$l_4+\alpha_4.l'_1$	$m_4+\alpha_4.m'_1$	$n_4+\alpha_4.n'_1$	$q_4+\alpha_4.q'_1$	$r_4+\alpha_4.r'_1$	$z_4+\alpha_4.z'_1$
$e_5+\alpha_5.e'_1$	$f_5+\alpha_5.f'_1$	$g_5+\alpha_5.g'_1$	$h_5+\alpha_5.h'_1$	$l_5+\alpha_5.l'_1$	$m_5+\alpha_5.m'_1$	$n_5+\alpha_5.n'_1$	$q_5+\alpha_5.q'_1$	$r_5+\alpha_5.r'_1$	$z_5+\alpha_5 z'_1$
$e_6+\alpha_6.e'_1$	$f_6+\alpha_6.f'_1$	$g_6+\alpha_6.g'_1$	$h_6+\alpha_6.h'_1$	$l_6+\alpha_6.l'_1$	$m_6+\alpha_6.m'_1$	$n_6+\alpha_6.n'_1$	$q_6+\alpha_6 q'_1$	$r_6+\alpha_6.r'_1$	$z_6+\alpha_6 z'_1$
$e_7+\alpha_7.e'_1$	$f_7+\alpha_7.f'_1$	$g_7+\alpha_7.g'_1$	$h_7+\alpha_7.h'_1$	$l_7+\alpha_7.l'_1$	$m_7+\alpha_7.m'_1$	$n_7+\alpha_7.n'_1$	$q_7+\alpha_7 q'_1$	$r_7+\alpha_7.r'_1$	$z_7+\alpha_7.z'_1$
$e_8+\alpha_8 e'_1$	$f_8+\alpha_8.f'_1$	$g_8+\alpha_8.g'_1$	$h_8+\alpha_8.h'_1$	$l_8+\alpha_8.l'_1$	$m_8+\alpha_8.m'_1$	$n_8+\alpha_8.n'_1$	$q_8+\alpha_8 q'_1$	$r_8+\alpha_8 r'_1$	$z_8+\alpha_8 z'_1$
$e_9+\alpha_9.e'_1$	$f_9+\alpha_9 f'_1$	$g_9+\alpha_9.g'_1$	$h_9+\alpha_9.h'_1$	$l_9+\alpha_9.l'_1$	$m_9+\alpha_9.m'_1$	$n_9+\alpha_9.n'_1$	$q_9+\alpha_9.q'_1$	$r_9+\alpha_9 r'_1$	$z_9+\alpha_9 z'_1$
$-e'_2\div\beta'_2$	$-f'_2\div\beta'_2$	$-g'_2\div\beta'_2$	$-h'_2\div\beta'_2$	$-l'_2\div\beta'_2$	$-m'_2-\beta'_2$	$-n'_2\div\beta'_2$	$-q'_2\div\beta'_2$	$-r'_2\div\beta'_2$	$-z'_2\div\beta'_2$
$e'_3+\beta'_3 e''_2$	$f'_3+\beta'_3.f''_2$	$g'_3+\beta'_3.g''_2$	$h'_3+\beta'_3.h''_2$	$l'_3+\beta'_3.l''_2$	$m'_3+\beta'_3.m''_2$	$n'_3+\beta'_3.n''_2$	$q'_3+\beta'_3.q''_2$	$r'_3+\beta'_3.r''_2$	$z'_3+\beta'_3.z''_2$
$e'_4+\beta'_4.e''_2$	$f'_4+\beta'_4.f''_2$	$g'_4+\beta'_4.g''_2$	$h'_4+\beta'_4.h''_2$	$l'_4+\beta'_4.l''_2$	$m'_4+\beta'_4.m''_2$	$n'_4+\beta'_4.n''_2$	$q'_4+\beta'_4.q''_2$	$r'_4+\beta'_4.r''_2$	$z'_4+\beta'_4.z''_2$
$e'_5+\beta'_5.e''_2$	$f'_5+\beta'_5.f''_2$	$g'_5+\beta'_5.g''_2$	$h'_5+\beta'_5.h''_2$	$l'_5+\beta'_5.l''_2$	$m'_5+\beta'_5.m''_2$	$n'_5+\beta'_5.n''_2$	$q'_5+\beta'_5.q''_2$	$r'_5+\beta'_5 r''_2$	$z'_5+\beta'_5.z''_2$
$e'_6+\beta'_6.e''_2$	$f'_6+\beta'_6.f''_2$	$g'_6+\beta'_6.g''_2$	$h'_6+\beta'_6.h''_2$	$l'_6+\beta'_6.l''_2$	$m'_6+\beta'_6 m''_2$	$n'_6+\beta'_6.n''_2$	$q'_6+\beta'_6.q''_2$	$r'_6+\beta'_6.r''_2$	$z'_6+\beta'_6.z''_2$
$e'_7+\beta'_7.e''_2$	$f'_7+\beta'_7.f''_2$	$g'_7+\beta'_7.g''_2$	$h'_7+\beta'_7.h''_2$	$l'_7+\beta'_7.l''_2$	$m'_7+\beta'_7.m''_2$	$n'_7+\beta'_7.n''_2$	$q'_7+\beta'_7 q''_2$	$r'_7+\beta'_7.r''_2$	$z'_7+\beta'_7.z''_2$
$e'_8+\beta'_8.e''_2$	$f'_8+\beta'_8.f''_2$	$g'_8+\beta'_8.g''_2$	$h'_8+\beta'_8.h''_2$	$l'_8+\beta'_8 l''_2$	$m'_8+\beta'_8 m''_2$	$n'_8+\beta'_8.n''_2$	$q'_8+\beta'_8.q''_2$	$r'_8+\beta'_8.r''_2$	$z'_8+\beta'_8.z''_2$
$e'_9+\beta'_9.e''_2$	$f'_9+\beta'_9.f''_2$	$g'_9+\beta'_9.g''_2$	$h'_9+\beta'_9.h''_2$	$l'_9+\beta'_9.l''_2$	$m'_9+\beta'_9.m''_2$	$n'_9+\beta'_9.n''_2$	$q'_9+\beta'_9.q''_2$	$r'_9+\beta'_9.r''_2$	$z'_9+\beta'_9.z''_2$
$-e''_3\div\gamma''_3$	$-f''_3\div\gamma''_3$	$-g''_3\div\gamma''_3$	$-h''_3\div\gamma''_3$	$-l''_3\div\gamma''_3$	$-m''_3\div\gamma''_3$	$-n''_3-\gamma''_3$	$-q''_3-\gamma''_3$	$-r''_3\div\gamma''_3$	$-z''_3\div\gamma''_3$
$e''_4+\gamma''_4.e'''_3$	$f''_4+\gamma''_4.f'''_3$	$g''_4+\gamma''_4.g'''_3$	$h''_4+\gamma''_4.h'''_3$	$l''_4+\gamma''_4.l'''_3$	$m''_4+\gamma''_4.m'''_3$	$n''_4+\gamma''_4.n'''_3$	$q''_4+\gamma''_4.q'''_3$	$r''_4+\gamma''_4.r'''_3$	$z''_4+\gamma''_4.z'''_3$
$e''_5+\gamma''_5.e'''_3$	$f''_5+\gamma''_5.f'''_3$	$g''_5+\gamma''_5.g'''_3$	$h''_5+\gamma''_5.h'''_3$	$l''_5+\gamma''_5.l'''_3$	$m''_5+\gamma''_5.m'''_3$	$n''_5+\gamma''_5.n'''_3$	$q''_5+\gamma''_5.q'''_3$	$r''_5+\gamma''_5.r'''_3$	$z''_5+\gamma''_5.z'''_3$
$e''_6+\gamma''_6.e'''_3$	$f''_6+\gamma''_6.f'''_3$	$g''_6+\gamma''_6.g'''_3$	$h''_6+\gamma''_6.h'''_3$	$l''_6+\gamma''_6.l'''_3$	$m''_6+\gamma''_6.m'''_3$	$n''_6+\gamma''_6.n'''_3$	$q''_6+\gamma''_6.q'''_3$	$r''_6+\gamma''_6.r'''_3$	$z''_6+\gamma''_6.z'''_3$
$e''_7+\gamma''_7.e'''_3$	$f''_7+\gamma''_7.f'''_3$	$g''_7+\gamma''_7.g'''_3$	$h''_7+\gamma''_7.h'''_3$	$l''_7+\gamma''_7.l'''_3$	$m''_7+\gamma''_7.m'''_3$	$n''_7+\gamma''_7.n'''_3$	$q''_7+\gamma''_7.q'''_3$	$r''_7+\gamma''_7.r'''_3$	$z''_7+\gamma''_7.z'''_3$
$e''_8+\gamma''_8.e'''_3$	$f''_8+\gamma''_8.f'''_3$	$g''_8+\gamma''_8.g'''_3$	$h''_8+\gamma''_8.h'''_3$	$l''_8+\gamma''_8.l'''_3$	$m''_8+\gamma''_8.m'''_3$	$n''_8+\gamma''_8.n'''_3$	$q''_8+\gamma''_8.q'''_3$	$r''_8+\gamma''_8.r'''_3$	$z''_8+\gamma''_8.z'''_3$
$e''_9+\gamma''_9.e'''_3$	$f''_9+\gamma''_9.f'''_3$	$g''_9+\gamma''_9.g'''_3$	$h''_9+\gamma''_9.h'''_3$	$l''_9+\gamma''_9.l'''_3$	$m''_9+\gamma''_9.m'''_3$	$n''_9+\gamma''_9.n'''_3$	$q''_9+\gamma''_9.q'''_3$	$r''_9+\gamma''_9.r'''_3$	$z''_9+\gamma''_9.z'''_3$
$-e'''_4\div\delta'''_4$	$-f'''_4\div\delta'''_4$	$-g'''_4-\delta'''_4$	$-h'''_4\div\delta'''_4$	$-l'''_4\div\delta'''_4$	$-m'''_4\div\delta'''_4$	$-n'''_4\div\delta'''_4$	$-q'''_4\div\delta'''_4$	$-r'''_4\div\delta'''_4$	$-z'''_4\div\delta'''_4$
$e'''_5+\delta'''_5.e^{iv}_4$	$f'''_5+\delta'''_5.f^{iv}_4$	$g'''_5+\delta'''_5.g^{iv}_4$	$h'''_5+\delta'''_5.h^{iv}_4$	$l'''_5+\delta'''_5.l^{iv}_4$	$m'''_5+\delta'''_5.m^{iv}_4$	$n'''_5+\delta'''_5 n^{iv}_4$	$q'''_5+\delta'''_5.q^{iv}_4$	$r'''_5+\delta'''_5.r^{iv}_4$	$z'''_5+\delta'''_5.z^{iv}_4$
$e'''_6+\delta'''_6.e^{iv}_4$	$f'''_6+\delta'''_6.f^{iv}_4$	$g'''_6+\delta'''_6.g^{iv}_4$	$h'''_6+\delta'''_6.h^{iv}_4$	$l'''_6+\delta'''_6.l^{iv}_4$	$m'''_6+\delta'''_6.m^{iv}_4$	$n'''_6+\delta'''_6.n^{iv}_4$	$q'''_6+\delta'''_6.q^{iv}_4$	$r'''_6+\delta'''_6.r^{iv}_4$	$z'''_6+\delta'''_6.z^{iv}_4$
$e'''_7+\delta'''_7.e^{iv}_4$	$f'''_7+\delta'''_7.f^{iv}_4$	$g'''_7+\delta'''_7.g^{iv}_4$	$h'''_7+\delta'''_7.h^{iv}_4$	$l'''_7+\delta'''_7.l^{iv}_4$	$m'''_7+\delta'''_7.m^{iv}_4$	$n'''_7+\delta'''_7.n^{iv}_4$	$q'''_7+\delta'''_7.q^{iv}_4$	$r'''_7+\delta'''_7.r^{iv}_4$	$z'''_7+\delta'''_7.z^{iv}_4$
$e'''_8+\delta'''_8.e^{iv}_4$	$f'''_8+\delta'''_8.f^{iv}_4$	$g'''_8+\delta'''_8.g^{iv}_4$	$h'''_8+\delta'''_8.h^{iv}_4$	$l'''_8+\delta'''_8.l^{iv}_4$	$m'''_8+\delta'''_8.m^{iv}_4$	$n'''_8+\delta'''_8.n^{iv}_4$	$q'''_8+\delta'''_8.q^{iv}_4$	$r'''_8+\delta'''_8.r^{iv}_4$	$z'''_8+\delta'''_8.z^{iv}_4$
$e'''_9+\delta'''_9.e^{iv}_4$	$f'''_9+\delta'''_9 f^{iv}_4$	$g'''_9+\delta'''_9 g^{iv}_4$	$h'''_9+\delta'''_9.h^{iv}_4$	$l'''_9+\delta'''_9.l^{iv}_4$	$m'''_9+\delta'''_9 m^{iv}_4$	$n'''_9+\delta'''_9.n^{iv}_4$	$q'''_9+\delta'''_9.q^{iv}_4$	$r'''_9+\delta'''_9.r^{iv}_4$	$z'''_9+\delta'''_9.z^{iv}_4$
$-e^{iv}_5\div\theta^{iv}_5$	$-f^{iv}_5\div\theta^{iv}_5$	$-g^{iv}_5\div\theta^{iv}_5$	$-h^{iv}_5\div\theta^{iv}_5$	$-l^{iv}_5\div\theta^{iv}_5$	$-m^{iv}_5\div\theta^{iv}_5$	$-n^{iv}_5\div\theta^{iv}_5$	$-q^{iv}_5\div\theta^{iv}_5$	$-r^{iv}_5\div\theta^{iv}_5$	$-z^{iv}_5\div\theta^{iv}_5$
$e^{iv}_6+\theta^{iv}_6.e^{v}_5$	$f^{iv}_6+\theta^{iv}_6.f^{v}_5$	$g^{iv}_6+\theta^{iv}_6.g^{v}_5$	$h^{iv}_6+\theta^{iv}_6.h^{v}_5$	$l^{iv}_6+\theta^{iv}_6.l^{v}_5$	$m^{iv}_6+\theta^{iv}_6.m^{v}_5$	$n^{iv}_6+\theta^{iv}_6.n^{v}_5$	$q^{iv}_6+\theta^{iv}_6.q^{v}_5$	$r^{iv}_6+\theta^{iv}_6.r^{v}_5$	$z^{iv}_6+\theta^{iv}_6.z^{v}_5$
$e^{iv}_7+\theta^{iv}_7.e^{v}_5$	$f^{iv}_7+\theta^{iv}_7.f^{v}_5$	$g^{iv}_7+\theta^{iv}_7.g^{v}_5$	$h^{iv}_7+\theta^{iv}_7.h^{v}_5$	$l^{iv}_7+\theta^{iv}_7.l^{v}_5$	$m^{iv}_7+\theta^{iv}_7.m^{v}_5$	$n^{iv}_7+\theta^{iv}_7.n^{v}_5$	$q^{iv}_7+\theta^{iv}_7.q^{v}_5$	$r^{iv}_7+\theta^{iv}_7.r^{v}_5$	$z^{iv}_7+\theta^{iv}_7.z^{v}_5$
$e^{iv}_8+\theta^{iv}_8.e^{v}_5$	$f^{iv}_8+\theta^{iv}_8.f^{v}_5$	$g^{iv}_8+\theta^{iv}_8.g^{v}_5$	$h^{iv}_8+\theta^{iv}_8.h^{v}_5$	$l^{iv}_8+\theta^{iv}_8.l^{v}_5$	$m^{iv}_8+\theta^{iv}_8.m^{v}_5$	$n^{iv}_8+\theta^{iv}_8.n^{v}_5$	$q^{iv}_8+\theta^{iv}_8.q^{v}_5$	$r^{iv}_8+\theta^{iv}_8.r^{v}_5$	$z^{iv}_8+\theta^{iv}_8.z^{v}_5$
$e^{iv}_9+\theta^{iv}_9.e^{v}_5$	$f^{iv}_9+\theta^{iv}_9.f^{v}_5$	$g^{iv}_9+\theta^{iv}_9.g^{v}_5$	$h^{iv}_9+\theta^{iv}_9.h^{v}_5$	$l^{iv}_9+\theta^{iv}_9.l^{v}_5$	$m^{iv}_9+\theta^{iv}_9.m^{v}_5$	$n^{iv}_9+\theta^{iv}_9.n^{v}_5$	$q^{iv}_9+\theta^{iv}_9.q^{v}_5$	$r^{iv}_9+\theta^{iv}_9.r^{v}_5$	$z^{iv}_9+\theta^{iv}_9.z^{v}_5$
$-e^{v}_6\div\phi^{v}_6$	$-f^{v}_6\div\phi^{v}_6$	$-g^{v}_6\div\phi^{v}_6$	$-h^{v}_6\div\phi^{v}_6$	$-l^{v}_6\div\phi^{v}_6$	$-m^{v}_6\div\phi^{v}_6$	$-n^{v}_6\div\phi^{v}_6$	$-q^{v}_6\div\phi^{v}_6$	$-r^{v}_6-\phi^{v}_6$	$-z^{v}_6\div\phi^{v}_6$
$e^{v}_7+\phi^{v}_7.e^{vi}_6$	$f^{v}_7+\phi^{v}_7.f^{vi}_6$	$g^{v}_7+\phi^{v}_7.g^{vi}_6$	$h^{v}_7+\phi^{v}_7.h^{vi}_6$	$l^{v}_7+\phi^{v}_7.l^{vi}_6$	$m^{v}_7+\phi^{v}_7.m^{vi}_6$	$n^{v}_7+\phi^{v}_7.n^{vi}_6$	$q^{v}_7+\phi^{v}_7.q^{vi}_6$	$r^{v}_7+\phi^{v}_7.r^{vi}_6$	$z^{v}_7+\phi^{v}_7.z^{vi}_6$
$e^{v}_8+\phi^{v}_8.e^{vi}_6$	$f^{v}_8+\phi^{v}_8.f^{vi}_6$	$g^{v}_8+\phi^{v}_8 g^{vi}_6$	$h^{v}_8+\phi^{v}_8.h^{vi}_6$	$l^{v}_8+\phi^{v}_8.l^{vi}_6$	$m^{v}_8+\phi^{v}_8 m^{vi}_6$	$n^{v}_8+\phi^{v}_8.n^{vi}_6$	$q^{v}_8+\phi^{v}_8 q^{vi}_6$	$r^{v}_8+\phi^{v}_8 r^{vi}_6$	$z^{v}_8+\phi^{v}_8.z^{vi}_6$
$e^{v}_9+\phi^{v}_9 e^{vi}_6$	$f^{v}_9+\phi^{v}_9.f^{vi}_6$	$g^{v}_9+\phi^{v}_9.g^{vi}_6$	$h^{v}_9+\phi^{v}_9.h^{vi}_6$	$l^{v}_9+\phi^{v}_9.l^{vi}_6$	$m^{v}_9+\phi^{v}_9.m^{vi}_6$	$n^{v}_9+\phi^{v}_9.n^{vi}_6$	$q^{v}_9+\phi^{v}_9.q^{vi}_6$	$r^{v}_9+\phi^{v}_9.r^{vi}_6$	$z^{v}_9+\phi^{v}_9 z^{vi}_6$
$-e^{vi}_7\div\psi^{vi}_7$	$-f^{vi}_7\div\psi^{vi}_7$	$-g^{vi}_7\div\psi^{vi}_7$	$-h^{vi}_7\div\psi^{vi}_7$	$-l^{vi}_7\div\psi^{vi}_7$	$-m^{vi}_7\div\psi^{vi}_7$	$-n^{vi}_7\div\psi^{vi}_7$	$-q^{vi}_7\div\psi^{vi}_7$	$-r^{vi}_7\div\psi^{vi}_7$	$-z^{vi}_7\div\psi^{vi}_7$
$e^{vi}_8+\psi^{vi}_8 e^{vii}_7$	$f^{vi}_8+\psi^{vi}_8.f^{vii}_7$	$g^{vi}_8+\psi^{vi}_8.g^{vii}_7$	$h^{vi}_8+\psi^{vi}_8.h^{vii}_7$	$l^{vi}_8+\psi^{vi}_8.l^{vii}_7$	$m^{vi}_8+\psi^{vi}_8 m^{vii}_7$	$n^{vi}_8+\psi^{vi}_8.n^{vii}_7$	$q^{vi}_8+\psi^{vi}_8.q^{vii}_7$	$r^{vi}_8+\psi^{vi}_8 r^{vii}_7$	$z^{vi}_8+\psi^{vi}_8 z^{vii}_7$
$e^{vi}_9+\psi^{vi}_9 e^{vii}_7$	$f^{vi}_9+\psi^{vi}_9.f^{vii}_7$	$g^{vi}_9+\psi^{vi}_9.g^{vii}_7$	$h^{vi}_9+\psi^{vi}_9.h^{vii}_7$	$l^{vi}_9+\psi^{vi}_9.l^{vii}_7$	$m^{vi}_9+\psi^{vi}_9.m^{vii}_7$	$n^{vi}_9+\psi^{vi}_9.n^{vii}_7$	$q^{vi}_9+\psi^{vi}_9.q^{vii}_7$	$r^{vi}_9+\psi^{vi}_9 r^{vii}_7$	$z^{vi}_9+\psi^{vi}_9 z^{vii}_7$
$-e^{vii}_8\div\epsilon^{vii}_8$	$-f^{vii}_8\div\epsilon^{vii}_8$	$-g^{vii}_8\div\epsilon^{vii}_8$	$-h^{vii}_8\div\epsilon^{vii}_8$	$-l^{vii}_8\div\epsilon^{vii}_8$	$-m^{vii}_8\div\epsilon^{vii}_8$	$-n^{vii}_8\div\epsilon^{vii}_8$	$-q^{vii}_8-\epsilon^{vii}_8$	$-r^{vii}_8\div\epsilon^{vii}_8$	$-z^{vii}_8\div\epsilon^{vii}_8$
$e^{vii}_9+\epsilon^{vii}_9.e^{viii}_8$	$f^{vii}_9+\epsilon^{vii}_9.f^{viii}_8$	$g^{vii}_9+\epsilon^{vii}_9.g^{viii}_8$	$h^{vii}_9+\epsilon^{vii}_9.h^{viii}_8$	$l^{vii}_9+\epsilon^{vii}_9.l^{viii}_8$	$m^{vii}_9+\epsilon^{vii}_9 m^{viii}_8$	$n^{vii}_9+\epsilon^{vii}_9 n^{viii}_8$	$q^{vii}_9+\epsilon^{vii}_9 q^{viii}_8$	$r^{vii}_9+\epsilon^{vii}_9 r^{viii}_8$	$z^{vii}_9+\epsilon^{vii}_9 z^{viii}_8$
$-e^{viii}_9\div\lambda^{viii}_9$	$-f^{viii}_9\div\lambda^{viii}_9$	$-g^{viii}_9\div\lambda^{viii}_9$	$-h^{viii}_9\div\lambda^{viii}_9$	$-l^{viii}_9\div\lambda^{viii}_9$	$-m^{viii}_9\div\lambda^{viii}_9$	$-n^{viii}_9\div\lambda^{viii}_9$	$-q^{viii}_9-\lambda^{viii}_9$	$-r^{viii}_9-\lambda^{viii}_9$	$-z^{viii}_9-\lambda^{viii}_9$

PLATE 12.

set down as calculated. Such a table with the values of all these coefficients is given in Plates 11 and 12. These plates are applicable to the solution for all stories except, of course, the coefficients in the first nine equations *A–a–*1, *A–b–*1, etc., values of which for the first and succeeding stories are discussed later. These calculations are of the very simplest kind and, with a Thacher rule, may be rapidly made.

In Plate 12 the term ω is expanded into its constituent terms, *i. e.*, into first story unknowns and a numerical term z. After calculating and tabulating the quantities as shown in Plates 11 and 12 it is seen that the bottom line gives V_0^C in terms of the terms comprised in ω only, *i. e.*, in first story unknowns and a numerical term. Now, by substituting this value of V_0^C in the value of V_0^B given on Plate 10, this quantity may also be found in terms of first story unknowns only. Then, using this value of V_0^B and the above value of V_0^C, substitute in the expression for S_0^C in Plate 10; continue thus until all the 0 story unknowns are given in terms of first story unknowns and the quantities z. The values of the coefficients of the first story unknowns and the numerical quantities, involved in these values of the 0 story unknowns, are given on Plate 13. Thus for the value of M_0^D, the coefficient of S_1^A is given in the column headed M_0^D and in the horizontal row marked on the left S_1^A. All the coefficients for any unknown are given in the vertical column headed by this unknown. The tables on Plate 13 have also been extended so as to give the coefficients for the values of C_1^A, C_1^B, C_1^C, C_1^D, Δ_0^a, Δ_0^b, Δ_0^d, C_2^A, C_2^B, C_2^C, C_2^D, Δ_1^a, Δ_1^b, and Δ_1^d, in terms of first story unknowns only. It is important to note the new symbol here introduced; for example $m^{\Delta-b}$ *with no subscript* means the value of the coefficient of S_1^B in the value of Δ_0^b when expressed in terms of first story unknowns only; also l^{V-B} represents the value of the coefficient of S_1^A in the expression for V_0^B. But quantities with subscripts as $o_1^{\Delta-b}$ represent the coefficients as already computed in plates 4, 5, 6, 7, and 8. These new coefficients may be properly associated by remembering that the letters are as in the original symbolic equations: thus e is a coefficient of M_1^A, l of S_1^A, m of s_1^B, etc.; and the exponents, as $\Delta - b$ for instance, refer to the quantity for the 0 story in the expression for the value of which the new

	V_0^C	V_0^B	S_0^C	S_0^B	S_0^A	M_0^D	M_0^C
M_1^A	e_9^{IX}	$e_8^{VIII}+\lambda_8^{VIII}e^{V-C}$	$e_7^{VII}+\varepsilon_7^{VII}e^{V-B}+\lambda_7^{VII}e^{V-C}$	$e_6^{VI}+\psi_6^{VI}e^{S-C}+\varepsilon_6^{VI}e^{V-B}+\lambda_6^{VI}e^{V-C}$	$e_5^{V}+\phi_5^{V}e^{S-B}+\psi_5^{V}e^{S-C}+\varepsilon_5^{V}e^{V-B}+\lambda_5^{V}e^{V-C}$	$e_4^{IV}+\theta_4^{IV}e^{S-A}+\phi_4^{IV}e^{S-B}+\psi_4^{IV}e^{S-C}+\varepsilon_4^{IV}e^{V-B}+\lambda_4^{IV}e^{V-C}$	$e_3'''+\delta_3'''e^{M-D}+\theta_3'''e^{S-A}+\phi_3'''e^{S-B}+\psi_3'''e^{S-C}+\varepsilon_3'''e^{V-B}+\lambda_3'''e^{V-C}$
M_1^B	f_9^{IX}	$f_8^{VIII}+\lambda_8^{VIII}f^{V-C}$	$f_7^{VII}+\varepsilon_7^{VII}f^{V-B}+\lambda_7^{VII}f^{V-C}$	$f_6^{VI}+\psi_6^{VI}f^{S-C}+\varepsilon_6^{VI}f^{V-B}+\lambda_6^{VI}f^{V-C}$	$f_5^{V}+\phi_5^{V}f^{S-B}+\psi_5^{V}f^{S-C}+\varepsilon_5^{V}f^{V-B}+\lambda_5^{V}f^{V-C}$	$f_4^{IV}+\theta_4^{IV}f^{S-A}+\phi_4^{IV}f^{S-B}+\psi_4^{IV}f^{S-C}+\varepsilon_4^{IV}f^{V-B}+\lambda_4^{IV}f^{V-C}$	$f_3'''+\delta_3'''f^{M-D}+\theta_3'''f^{S-A}+\phi_3'''f^{S-B}+\psi_3'''f^{S-C}+\varepsilon_3'''f^{V-B}+\lambda_3'''f^{V-C}$
M_1^C	g_9^{IX}	$g_8^{VIII}+\lambda_8^{VIII}g^{V-C}$	$g_7^{VII}+\varepsilon_7^{VII}g^{V-B}+\lambda_7^{VII}g^{V-C}$	$g_6^{VI}+\psi_6^{VI}g^{S-C}+\varepsilon_6^{VI}g^{V-B}+\lambda_6^{VI}g^{V-C}$	$g_5^{V}+\phi_5^{V}g^{S-B}+\psi_5^{V}g^{S-C}+\varepsilon_5^{V}g^{V-B}+\lambda_5^{V}g^{V-C}$	$g_4^{IV}+\theta_4^{IV}g^{S-A}+\phi_4^{IV}g^{S-B}+\psi_4^{IV}g^{S-C}+\varepsilon_4^{IV}g^{V-B}+\lambda_4^{IV}g^{V-C}$	$g_3'''+\delta_3'''g^{M-D}+\theta_3'''g^{S-A}+\phi_3'''g^{S-B}+\psi_3'''g^{S-C}+\varepsilon_3'''g^{V-B}+\lambda_3'''g^{V-C}$
M_1^D	h_9^{IX}	$h_8^{VIII}+\lambda_8^{VIII}h^{V-C}$	$h_7^{VII}+\varepsilon_7^{VII}h^{V-B}+\lambda_7^{VII}h^{V-C}$	$h_6^{VI}+\psi_6^{VI}h^{S-C}+\varepsilon_6^{VI}h^{V-B}+\lambda_6^{VI}h^{V-C}$	$h_5^{V}+\phi_5^{V}h^{S-B}+\psi_5^{V}h^{S-C}+\varepsilon_5^{V}h^{V-B}+\lambda_5^{V}h^{V-C}$	$h_4^{IV}+\theta_4^{IV}h^{S-A}+\phi_4^{IV}h^{S-B}+\psi_4^{IV}h^{S-C}+\varepsilon_4^{IV}h^{V-B}+\lambda_4^{IV}h^{V-C}$	$h_3'''+\delta_3'''h^{M-D}+\theta_3'''h^{S-A}+\phi_3'''h^{S-B}+\psi_3'''h^{S-C}+\varepsilon_3'''h^{V-B}+\lambda_3'''h^{V-C}$
S_1^A	l_9^{IX}	$l_8^{VIII}+\lambda_8^{VIII}l^{V-C}$	$l_7^{VII}+\varepsilon_7^{VII}l^{V-B}+\lambda_7^{VII}l^{V-C}$	$l_6^{VI}+\psi_6^{VI}l^{S-C}+\varepsilon_6^{VI}l^{V-B}+\lambda_6^{VI}l^{V-C}$	$l_5^{V}+\phi_5^{V}l^{S-B}+\psi_5^{V}l^{S-C}+\varepsilon_5^{V}l^{V-B}+\lambda_5^{V}l^{V-C}$	$l_4^{IV}+\theta_4^{IV}l^{S-A}+\phi_4^{IV}l^{S-B}+\psi_4^{IV}l^{S-C}+\varepsilon_4^{IV}l^{V-B}+\lambda_4^{IV}l^{V-C}$	$l_3'''+\delta_3'''l^{M-D}+\theta_3'''l^{S-A}+\phi_3'''l^{S-B}+\psi_3'''l^{S-C}+\varepsilon_3'''l^{V-B}+\lambda_3'''l^{V-C}$
S_1^B	m_9^{IX}	$m_8^{VIII}+\lambda_8^{VIII}m^{V-C}$	$m_7^{VII}+\varepsilon_7^{VII}m^{V-B}+\lambda_7^{VII}m^{V-C}$	$m_6^{VI}+\psi_6^{VI}m^{S-C}+\varepsilon_6^{VI}m^{V-B}+\lambda_6^{VI}m^{V-C}$	$m_5^{V}+\phi_5^{V}m^{S-B}+\psi_5^{V}m^{S-C}+\varepsilon_5^{V}m^{V-B}+\lambda_5^{V}m^{V-C}$	$m_4^{IV}+\theta_4^{IV}m^{S-A}+\phi_4^{IV}m^{S-B}+\psi_4^{IV}m^{S-C}+\varepsilon_4^{IV}m^{V-B}+\lambda_4^{IV}m^{V-C}$	$m_3'''+\delta_3'''m^{M-D}+\theta_3'''m^{S-A}+\phi_3'''m^{S-B}+\psi_3'''m^{S-C}+\varepsilon_3'''m^{V-B}+\lambda_3'''m^{V-C}$
S_1^C	n_9^{IX}	$n_8^{VIII}+\lambda_8^{VIII}n^{V-C}$	$n_7^{VII}+\varepsilon_7^{VII}n^{V-B}+\lambda_7^{VII}n^{V-C}$	$n_6^{VI}+\psi_6^{VI}n^{S-C}+\varepsilon_6^{VI}n^{V-B}+\lambda_6^{VI}n^{V-C}$	$n_5^{V}+\phi_5^{V}n^{S-B}+\psi_5^{V}n^{S-C}+\varepsilon_5^{V}n^{V-B}+\lambda_5^{V}n^{V-C}$	$n_4^{IV}+\theta_4^{IV}n^{S-A}+\phi_4^{IV}n^{S-B}+\psi_4^{IV}n^{S-C}+\varepsilon_4^{IV}n^{V-B}+\lambda_4^{IV}n^{V-C}$	$n_3'''+\delta_3'''n^{M-D}+\theta_3'''n^{S-A}+\phi_3'''n^{S-B}+\psi_3'''n^{S-C}+\varepsilon_3'''n^{V-B}+\lambda_3'''n^{V-C}$
V_1^B	q_9^{IX}	$q_8^{VIII}+\lambda_8^{VIII}q^{V-C}$	$q_7^{VII}+\varepsilon_7^{VII}q^{V-B}+\lambda_7^{VII}q^{V-C}$	$q_6^{VI}+\psi_6^{VI}q^{S-C}+\varepsilon_6^{VI}q^{V-B}+\lambda_6^{VI}q^{V-C}$	$q_5^{V}+\phi_5^{V}q^{S-B}+\psi_5^{V}q^{S-C}+\varepsilon_5^{V}q^{V-B}+\lambda_5^{V}q^{V-C}$	$q_4^{IV}+\theta_4^{IV}q^{S-A}+\phi_4^{IV}q^{S-B}+\psi_4^{IV}q^{S-C}+\varepsilon_4^{IV}q^{V-B}+\lambda_4^{IV}q^{V-C}$	$q_3'''+\delta_3'''q^{M-D}+\theta_3'''q^{S-A}+\phi_3'''q^{S-B}+\psi_3'''q^{S-C}+\varepsilon_3'''q^{V-B}+\lambda_3'''q^{V-C}$
V_1^C	r_9^{IX}	$r_8^{VIII}+\lambda_8^{VIII}r^{V-C}$	$r_7^{VII}+\varepsilon_7^{VII}r^{V-B}+\lambda_7^{VII}r^{V-C}$	$r_6^{VI}+\psi_6^{VI}r^{S-C}+\varepsilon_6^{VI}r^{V-B}+\lambda_6^{VI}r^{V-C}$	$r_5^{V}+\phi_5^{V}r^{S-B}+\psi_5^{V}r^{S-C}+\varepsilon_5^{V}r^{V-B}+\lambda_5^{V}r^{V-C}$	$r_4^{IV}+\theta_4^{IV}r^{S-A}+\phi_4^{IV}r^{S-B}+\psi_4^{IV}r^{S-C}+\varepsilon_4^{IV}r^{V-B}+\lambda_4^{IV}r^{V-C}$	$r_3'''+\delta_3'''r^{M-D}+\theta_3'''r^{S-A}+\phi_3'''r^{S-B}+\psi_3'''r^{S-C}+\varepsilon_3'''r^{V-B}+\lambda_3'''r^{V-C}$
z	z_9^{IX}	$z_8^{VIII}+\lambda_8^{VIII}z^{V-C}$	$z_7^{VII}+\varepsilon_7^{VII}z^{V-B}+\lambda_7^{VII}z^{V-C}$	$z_6^{VI}+\psi_6^{VI}z^{S-C}+\varepsilon_6^{VI}z^{V-B}+\lambda_6^{VI}z^{V-C}$	$z_5^{V}+\phi_5^{V}z^{S-B}+\psi_5^{V}z^{S-C}+\varepsilon_5^{V}z^{V-B}+\lambda_5^{V}z^{V-C}$	$z_4^{IV}+\theta_4^{IV}z^{S-A}+\phi_4^{IV}z^{S-B}+\psi_4^{IV}z^{S-C}+\varepsilon_4^{IV}z^{V-B}+\lambda_4^{IV}z^{V-C}$	$z_3'''+\delta_3'''z^{M-D}+\theta_3'''z^{S-A}+\phi_3'''z^{S-B}+\psi_3'''z^{S-C}+\varepsilon_3'''z^{V-B}+\lambda_3'''z^{V-C}$

	M_0^B	M_0^A	C_1^A	C_1^B	C_1^C
M_1^A	$e_2''+\gamma_2''e^{M-C}+\delta_2''e^{M-D}+\theta_2''e^{S-A}+\phi_2''e^{S-B}+\psi_2''e^{S-C}+\varepsilon_2''e^{V-B}+\lambda_2''e^{V-C}$	$e_1'+\beta_1'e^{M-B}+\gamma_1'e^{M-C}+\delta_1'e^{M-D}+\theta_1'e^{S-A}+\phi_1'e^{S-B}+\psi_1'e^{S-C}+\varepsilon_1'e^{V-B}+\lambda_1'e^{V-C}$	$a_0^{C-A}e^{M-A}+l_0^{C-A}e^{S-A}$	$b_0^{C-B}e^{M-B}+j_0^{C-B}e^{S-B}$	$c_0^{C-C}e^{M-C}+k_0^{C-C}e^{S-C}$
M_1^B	$f_2''+\gamma_2''f^{M-C}+\delta_2''f^{M-D}+\theta_2''f^{S-A}+\phi_2''f^{S-B}+\psi_2''f^{S-C}+\varepsilon_2''f^{V-B}+\lambda_2''f^{V-C}$	$f_1'+\beta_1'f^{M-B}+\gamma_1'f^{M-C}+\delta_1'f^{M-D}+\theta_1'f^{S-A}+\phi_1'f^{S-B}+\psi_1'f^{S-C}+\varepsilon_1'f^{V-B}+\lambda_1'f^{V-C}$	$a_0^{C-A}f^{M-A}+l_0^{C-A}f^{S-A}$	$b_0^{C-B}f^{M-B}+j_0^{C-B}f^{S-B}$	$c_0^{C-C}f^{M-C}+k_0^{C-C}f^{S-C}$
M_1^C	$g_2''+\gamma_2''g^{M-C}+\delta_2''g^{M-D}+\theta_2''g^{S-A}+\phi_2''g^{S-B}+\psi_2''g^{S-C}+\varepsilon_2''g^{V-B}+\lambda_2''g^{V-C}$	$g_1'+\beta_1'g^{M-B}+\gamma_1'g^{M-C}+\delta_1'g^{M-D}+\theta_1'g^{S-A}+\phi_1'g^{S-B}+\psi_1'g^{S-C}+\varepsilon_1'g^{V-B}+\lambda_1'g^{V-C}$	$a_0^{C-A}g^{M-A}+l_0^{C-A}g^{S-A}$	$b_0^{C-B}g^{M-B}+j_0^{C-B}g^{S-B}$	$c_0^{C-C}g^{M-C}+k_0^{C-C}g^{S-C}$
M_1^D	$h_2''+\gamma_2''h^{M-C}+\delta_2''h^{M-D}+\theta_2''h^{S-A}+\phi_2''h^{S-B}+\psi_2''h^{S-C}+\varepsilon_2''h^{V-B}+\lambda_2''h^{V-C}$	$h_1'+\beta_1'h^{M-B}+\gamma_1'h^{M-C}+\delta_1'h^{M-D}+\theta_1'h^{S-A}+\phi_1'h^{S-B}+\psi_1'h^{S-C}+\varepsilon_1'h^{V-B}+\lambda_1'h^{V-C}$	$a_0^{C-A}h^{M-A}+l_0^{C-A}h^{S-A}$	$b_0^{C-B}h^{M-B}+j_0^{C-B}h^{S-B}$	$c_0^{C-C}h^{M-C}+k_0^{C-C}h^{S-C}$
S_1^A	$l_2''+\gamma_2''l^{M-C}+\delta_2''l^{M-D}+\theta_2''l^{S-A}+\phi_2''l^{S-B}+\psi_2''l^{S-C}+\varepsilon_2''l^{V-B}+\lambda_2''l^{V-C}$	$l_1'+\beta_1'l^{M-B}+\gamma_1'l^{M-C}+\delta_1'l^{M-D}+\theta_1'l^{S-A}+\phi_1'l^{S-B}+\psi_1'l^{S-C}+\varepsilon_1'l^{V-B}+\lambda_1'l^{V-C}$	$a_0^{C-A}l^{M-A}+l_0^{C-A}l^{S-A}$	$b_0^{C-B}l^{M-B}+j_0^{C-B}l^{S-B}$	$c_0^{C-C}l^{M-C}+k_0^{C-C}l^{S-C}$
S_1^B	$m_2''+\gamma_2''m^{M-C}+\delta_2''m^{M-D}+\theta_2''m^{S-A}+\phi_2''m^{S-B}+\psi_2''m^{S-C}+\varepsilon_2''m^{V-B}+\lambda_2''m^{V-C}$	$m_1'+\beta_1'm^{M-B}+\gamma_1'm^{M-C}+\delta_1'm^{M-D}+\theta_1'm^{S-A}+\phi_1'm^{S-B}+\psi_1'm^{S-C}+\varepsilon_1'm^{V-B}+\lambda_1'm^{V-C}$	$a_0^{C-A}m^{M-A}+l_0^{C-A}m^{S-A}$	$b_0^{C-B}m^{M-B}+j_0^{C-B}m^{S-B}$	$c_0^{C-C}m^{M-C}+k_0^{C-C}m^{S-C}$
S_1^C	$n_2''+\gamma_2''n^{M-C}+\delta_2''n^{M-D}+\theta_2''n^{S-A}+\phi_2''n^{S-B}+\psi_2''n^{S-C}+\varepsilon_2''n^{V-B}+\lambda_2''n^{V-C}$	$n_1'+\beta_1'n^{M-B}+\gamma_1'n^{M-C}+\delta_1'n^{M-D}+\theta_1'n^{S-A}+\phi_1'n^{S-B}+\psi_1'n^{S-C}+\varepsilon_1'n^{V-B}+\lambda_1'n^{V-C}$	$a_0^{C-A}n^{M-A}+l_0^{C-A}n^{S-A}$	$b_0^{C-B}n^{M-B}+j_0^{C-B}n^{S-B}$	$c_0^{C-C}n^{M-C}+k_0^{C-C}n^{S-C}$
V_1^B	$q_2''+\gamma_2''q^{M-C}+\delta_2''q^{M-D}+\theta_2''q^{S-A}+\phi_2''q^{S-B}+\psi_2''q^{S-C}+\varepsilon_2''q^{V-B}+\lambda_2''q^{V-C}$	$q_1'+\beta_1'q^{M-B}+\gamma_1'q^{M-C}+\delta_1'q^{M-D}+\theta_1'q^{S-A}+\phi_1'q^{S-B}+\psi_1'q^{S-C}+\varepsilon_1'q^{V-B}+\lambda_1'q^{V-C}$	$a_0^{C-A}q^{M-A}+l_0^{C-A}q^{S-A}$	$b_0^{C-B}q^{M-B}+j_0^{C-B}q^{S-B}$	$c_0^{C-C}q^{M-C}+k_0^{C-C}q^{S-C}$
V_1^C	$r_2''+\gamma_2''r^{M-C}+\delta_2''r^{M-D}+\theta_2''r^{S-A}+\phi_2''r^{S-B}+\psi_2''r^{S-C}+\varepsilon_2''r^{V-B}+\lambda_2''r^{V-C}$	$r_1'+\beta_1'r^{M-B}+\gamma_1'r^{M-C}+\delta_1'r^{M-D}+\theta_1'r^{S-A}+\phi_1'r^{S-B}+\psi_1'r^{S-C}+\varepsilon_1'r^{V-B}+\lambda_1'r^{V-C}$	$a_0^{C-A}r^{M-A}+l_0^{C-A}r^{S-A}$	$b_0^{C-B}r^{M-B}+j_0^{C-B}r^{S-B}$	$c_0^{C-C}r^{M-C}+k_0^{C-C}r^{S-C}$
z	$z_2''+\gamma_2''z^{M-C}+\delta_2''z^{M-D}+\theta_2''z^{S-A}+\phi_2''z^{S-B}+\psi_2''z^{S-C}+\varepsilon_2''z^{V-B}+\lambda_2''z^{V-C}$	$z_1'+\beta_1'z^{M-B}+\gamma_1'z^{M-C}+\delta_1'z^{M-D}+\theta_1'z^{S-A}+\phi_1'z^{S-B}+\psi_1'z^{S-C}+\varepsilon_1'z^{V-B}+\lambda_1'z^{V-C}$	$a_0^{C-A}z^{M-A}+l_0^{C-A}z^{S-A}$	$b_0^{C-B}z^{M-B}+j_0^{C-B}z^{S-B}$	$c_0^{C-C}z^{M-C}+k_0^{C-C}z^{S-C}$

	C_1^D	Δ_0^a	Δ_0^b	Δ_0^d
M_1^A	$d_0^{C-D}e^{M-D}+l_0^{C-D}e^{S-A}+j_0^{C-D}e^{S-B}+k_0^{C-D}e^{S-C}$	$a_0^{\Delta-a}e^{M-A}+b_0^{\Delta-a}e^{M-B}+c_0^{\Delta-a}e^{M-C}+d_0^{\Delta-a}e^{M-D}+o_0^{\Delta-a}e^{V-B}+p_0^{\Delta-a}e^{V-C}$	$o_0^{\Delta-b}e^{V-B}+p_0^{\Delta-b}e^{V-C}$	$a_0^{\Delta-d}e^{M-A}+b_0^{\Delta-d}e^{M-B}+c_0^{\Delta-d}e^{M-C}+d_0^{\Delta-d}e^{M-D}+o_0^{\Delta-d}e^{V-B}+p_0^{\Delta-d}e^{V-C}$
M_1^B	$d_0^{C-D}f^{M-D}+l_0^{C-D}f^{S-A}+j_0^{C-D}f^{S-B}+k_0^{C-D}f^{S-C}$	$a_0^{\Delta-a}f^{M-A}+b_0^{\Delta-a}f^{M-B}+c_0^{\Delta-a}f^{M-C}+d_0^{\Delta-a}f^{M-D}+o_0^{\Delta-a}f^{V-B}+p_0^{\Delta-a}f^{V-C}$	$o_0^{\Delta-b}f^{V-B}+p_0^{\Delta-b}f^{V-C}$	$a_0^{\Delta-d}f^{M-A}+b_0^{\Delta-d}f^{M-B}+c_0^{\Delta-d}f^{M-C}+d_0^{\Delta-d}f^{M-D}+o_0^{\Delta-d}f^{V-B}+p_0^{\Delta-d}f^{V-C}$
M_1^C	$d_0^{C-D}g^{M-D}+l_0^{C-D}g^{S-A}+j_0^{C-D}g^{S-B}+k_0^{C-D}g^{S-C}$	$a_0^{\Delta-a}g^{M-A}+b_0^{\Delta-a}g^{M-B}+c_0^{\Delta-a}g^{M-C}+d_0^{\Delta-a}g^{M-D}+o_0^{\Delta-a}g^{V-B}+p_0^{\Delta-a}g^{V-C}$	$o_0^{\Delta-b}g^{V-B}+p_0^{\Delta-b}g^{V-C}$	$a_0^{\Delta-d}g^{M-A}+b_0^{\Delta-d}g^{M-B}+c_0^{\Delta-d}g^{M-C}+d_0^{\Delta-d}g^{M-D}+o_0^{\Delta-d}g^{V-B}+p_0^{\Delta-d}g^{V-C}$
M_1^D	$d_0^{C-D}h^{M-D}+l_0^{C-D}h^{S-A}+j_0^{C-D}h^{S-B}+k_0^{C-D}h^{S-C}$	$a_0^{\Delta-a}h^{M-A}+b_0^{\Delta-a}h^{M-B}+c_0^{\Delta-a}h^{M-C}+d_0^{\Delta-a}h^{M-D}+o_0^{\Delta-a}h^{V-B}+p_0^{\Delta-a}h^{V-C}$	$o_0^{\Delta-b}h^{V-B}+p_0^{\Delta-b}h^{V-C}$	$a_0^{\Delta-d}h^{M-A}+b_0^{\Delta-d}h^{M-B}+c_0^{\Delta-d}h^{M-C}+d_0^{\Delta-d}h^{M-D}+o_0^{\Delta-d}h^{V-B}+p_0^{\Delta-d}h^{V-C}$
S_1^A	$d_0^{C-D}l^{M-D}+l_0^{C-D}l^{S-A}+j_0^{C-D}l^{S-B}+k_0^{C-D}l^{S-C}$	$a_0^{\Delta-a}l^{M-A}+b_0^{\Delta-a}l^{M-B}+c_0^{\Delta-a}l^{M-C}+d_0^{\Delta-a}l^{M-D}+o_0^{\Delta-a}l^{V-B}+p_0^{\Delta-a}l^{V-C}$	$o_0^{\Delta-b}l^{V-B}+p_0^{\Delta-b}l^{V-C}$	$a_0^{\Delta-d}l^{M-A}+b_0^{\Delta-d}l^{M-B}+c_0^{\Delta-d}l^{M-C}+d_0^{\Delta-d}l^{M-D}+o_0^{\Delta-d}l^{V-B}+p_0^{\Delta-d}l^{V-C}$
S_1^B	$d_0^{C-D}m^{M-D}+l_0^{C-D}m^{S-A}+j_0^{C-D}m^{S-B}+k_0^{C-D}m^{S-C}$	$a_0^{\Delta-a}m^{M-A}+b_0^{\Delta-a}m^{M-B}+c_0^{\Delta-a}m^{M-C}+d_0^{\Delta-a}m^{M-D}+o_0^{\Delta-a}m^{V-B}+p_0^{\Delta-a}m^{V-C}$	$o_0^{\Delta-b}m^{V-B}+p_0^{\Delta-b}m^{V-C}$	$a_0^{\Delta-d}m^{M-A}+b_0^{\Delta-d}m^{M-B}+c_0^{\Delta-d}m^{M-C}+d_0^{\Delta-d}m^{M-D}+o_0^{\Delta-d}m^{V-B}+p_0^{\Delta-d}m^{V-C}$
S_1^C	$d_0^{C-D}n^{M-D}+l_0^{C-D}n^{S-A}+j_0^{C-D}n^{S-B}+k_0^{C-D}n^{S-C}$	$a_0^{\Delta-a}n^{M-A}+b_0^{\Delta-a}n^{M-B}+c_0^{\Delta-a}n^{M-C}+d_0^{\Delta-a}n^{M-D}+o_0^{\Delta-a}n^{V-B}+p_0^{\Delta-a}n^{V-C}$	$o_0^{\Delta-b}n^{V-B}+p_0^{\Delta-b}n^{V-C}$	$a_0^{\Delta-d}n^{M-A}+b_0^{\Delta-d}n^{M-B}+c_0^{\Delta-d}n^{M-C}+d_0^{\Delta-d}n^{M-D}+o_0^{\Delta-d}n^{V-B}+p_0^{\Delta-d}n^{V-C}$
V_1^B	$d_0^{C-D}q^{M-D}+l_0^{C-D}q^{S-A}+j_0^{C-D}q^{S-B}+k_0^{C-D}q^{S-C}$	$a_0^{\Delta-a}q^{M-A}+b_0^{\Delta-a}q^{M-B}+c_0^{\Delta-a}q^{M-C}+d_0^{\Delta-a}q^{M-D}+o_0^{\Delta-a}q^{V-B}+p_0^{\Delta-a}q^{V-C}$	$o_0^{\Delta-b}q^{V-B}+p_0^{\Delta-b}q^{V-C}$	$a_0^{\Delta-d}q^{M-A}+b_0^{\Delta-d}q^{M-B}+c_0^{\Delta-d}q^{M-C}+d_0^{\Delta-d}q^{M-D}+o_0^{\Delta-d}q^{V-B}+p_0^{\Delta-d}q^{V-C}$
V_1^C	$d_0^{C-D}r^{M-D}+l_0^{C-D}r^{S-A}+j_0^{C-D}r^{S-B}+k_0^{C-D}r^{S-C}$	$a_0^{\Delta-a}r^{M-A}+b_0^{\Delta-a}r^{M-B}+c_0^{\Delta-a}r^{M-C}+d_0^{\Delta-a}r^{M-D}+o_0^{\Delta-a}r^{V-B}+p_0^{\Delta-a}r^{V-C}$	$o_0^{\Delta-b}r^{V-B}+p_0^{\Delta-b}r^{V-C}$	$a_0^{\Delta-d}r^{M-A}+b_0^{\Delta-d}r^{M-B}+c_0^{\Delta-d}r^{M-C}+d_0^{\Delta-d}r^{M-D}+o_0^{\Delta-d}r^{V-B}+p_0^{\Delta-d}r^{V-C}$
z	$z_0^{C-D}+d_0^{C-D}z^{M-D}+l_0^{C-D}z^{S-A}+j_0^{C-D}z^{S-B}+k_0^{C-D}z^{S-C}$	$z_0^{\Delta-a}+a_0^{\Delta-a}z^{M-A}+b_0^{\Delta-a}z^{M-B}+c_0^{\Delta-a}z^{M-C}+d_0^{\Delta-a}z^{M-D}+o_0^{\Delta-a}z^{V-B}+p_0^{\Delta-a}z^{V-C}$	$o_0^{\Delta-b}z^{V-B}+p_0^{\Delta-b}z^{V-C}$	$z_0^{\Delta-d}+a_0^{\Delta-d}z^{M-A}+b_0^{\Delta-d}z^{M-B}+c_0^{\Delta-d}z^{M-C}+d_0^{\Delta-d}z^{M-D}+o_0^{\Delta-d}z^{V-B}+p_0^{\Delta-d}z^{V-C}$

	C_2^A	C_2^B	C_2^C	C_2^D	Δ_1^a	Δ_1^b	Δ_1^d
M_1^A	$a_1^{C-A}+e^{C-A}$	e^{C-B}	e^{C-C}	e^{C-D}	$a_1^{\Delta-a}+e^{\Delta-a}$	$e^{\Delta-b}$	$a_1^{\Delta-d}+e^{\Delta-d}$
M_1^B	f^{C-A}	$b_1^{C-B}+f^{C-B}$	f^{C-C}	f^{C-D}	$b_1^{\Delta-a}+f^{\Delta-a}$	$f^{\Delta-b}$	$b_1^{\Delta-d}+f^{\Delta-d}$
M_1^C	g^{C-A}	g^{C-B}	$c_1^{C-C}+g^{C-C}$	g^{C-D}	$c_1^{\Delta-a}+g^{\Delta-a}$	$g^{\Delta-b}$	$c_1^{\Delta-d}+g^{\Delta-d}$
M_1^D	h^{C-A}	h^{C-B}	h^{C-C}	$d_1^{C-D}+h^{C-D}$	$d_1^{\Delta-a}+h^{\Delta-a}$	$h^{\Delta-b}$	$d_1^{\Delta-d}+h^{\Delta-d}$
S_1^A	$l_1^{C-A}+l^{C-A}$	l^{C-B}	l^{C-C}	$l_1^{C-D}+l^{C-D}$	$l^{\Delta-a}$	$l^{\Delta-b}$	$l^{\Delta-d}$
S_1^B	m^{C-A}	$j_1^{C-B}+m^{C-B}$	m^{C-C}	$j_1^{C-D}+m^{C-D}$	$m^{\Delta-a}$	$m^{\Delta-b}$	$m^{\Delta-d}$
S_1^C	n^{C-A}	n^{C-B}	$k_1^{C-C}+n^{C-C}$	$k_1^{C-D}+n^{C-D}$	$n^{\Delta-a}$	$n^{\Delta-b}$	$n^{\Delta-d}$
V_1^B	q^{C-A}	q^{C-B}	q^{C-C}	q^{C-D}	$o_1^{\Delta-a}+q^{\Delta-a}$	$o_1^{\Delta-b}+q^{\Delta-b}$	$o_1^{\Delta-d}+q^{\Delta-d}$
V_1^C	r^{C-A}	r^{C-B}	r^{C-C}	r^{C-D}	$p_1^{\Delta-a}+r^{\Delta-a}$	$p_1^{\Delta-b}+r^{\Delta-b}$	$p_1^{\Delta-d}+r^{\Delta-d}$
z	z^{C-A}	z^{C-B}	z^{C-C}	$z_1^{C-D}+z^{C-D}$	$z_1^{\Delta-a}+z^{\Delta-a}$	$z^{\Delta-b}$	$z_1^{\Delta-d}+z^{\Delta-d}$

TABLES GIVING VALUES OF QUANTITIES IN TERMS OF THE FIRST STORY UNKNOWNS

Note. For other stories use the same table, changing only the subscripts of the unknowns and of the coefficients of the Symbolic Equations to agree with the story, with exceptions as noted in Text.

PLATE 13.

coefficient is found. Calculating and tabulating the quantities as shown on Plate 13 finishes the solution for the 0 story.

Now, in starting the solution for the first story to express first, story unknowns in terms of second story unknowns the values of α, β, γ, δ, θ, φ, ψ, ϵ, λ, and z for the nine equations A–a–1, A–b–1, etc., must be found before starting the tables of Plates 11 and 12. The rest of the coefficients involved in the term ω, *i. e.*, the coefficients of second story unknowns, will be as shown on Plate 12 except that the subscripts will be 2 instead of 1. Now, referring to the symbolic equations A_1^a, A_1^b, A_1^d, B_1^a, B_1^b, B_1^d, C_1^a, C_1^b, and C_1^d it will be seen that the other quantities α, β, γ, etc., would also be as given in Plates 11 and 12 with only a change of subscript were it not for the additional terms $s_1^{A-a}C_1^A + t_1^{A-a}C_1^B + P_1^{A-a}S_0^A$ in equation A_1^a, $t_1^{A-b}C_1^B + u_1^{A-b}C_1^C + P_1^{A-b}S_0^A + Q_1^{A-b}S_0^B$ in equation A_1^b, $u_1^{A-d}C_1^C + v_1^{A-d}C_1^D + P_1^{A-d}S_0^A + Q_1^{A-d}S_0^B + R_1^{A-d}S_0^C$ in equation A_1^d, $s_1^{B-a}C_1^A + t_1^{B-a}C_1^B$ in equation B_1^a, $t_1^{B-b}C_1^B + u_1^{B-b}C_1^C$ in equation B_1^b, $u_1^{B-d}C_1^C + v_1^{B-d}C_1^D$ in equation B_1^d, $w_1^{C-a}\Delta_0^a + t_1^{C-a}C_1^B$ in equation C_1^a, $x_1^{C-b}\Delta_0^b + u_1^{C-b}C_1^C$ in equation C_1^b, and $y_1^{C-d}\Delta_0^d + v_1^{C-d}C_1^D$ in equation C_1^d.

Now, on Plate 13 is given the values of all these terms C_1^A, C_1^B, C_1^C, C_1^D, Δ_0^a, Δ_0^b, and Δ_0^d in terms of first story unknowns only. Therefore the coefficients α, β, γ, etc., in equations A–a–1, A–b–1, etc., may be made up as were those for C_2^A, C_2^B, etc., as given on Plate 13: thus α_1 would be $a_1^{A-a} + s_1^{A-a}e^{C-A} + t_1^{A-a}e^{C-B} + P_1^{A-a}e^{s-A}$; α_4 would be $a_1^{B-a} + s_1^{B-a}h^{C-A} + t_1^{B-a}h^{C-B}$, etc. In this manner the coefficients for the nine equations A–a–1, A–b–1, etc., may be easily computed and then the tables on Plates 11, 12, and 13 may be computed up as far as the value of C_1^A on Plate 13 (would be C_2^A for first story). The values of C_2^A, C_2^B, C_2^C, C_2^D, Δ_1^a, Δ_1^b, and Δ_1^d must be known in terms of second story unknowns before the coefficients α, β, γ, etc., can be computed for starting the solution for the second story; just as the values of C_1^A, C_1^B, C_1^C, C_1^D, Δ_0^a, Δ_0^b, and Δ_0^d were needed for preparing for the first story solution. But, on Plate 13 of the 0 story solution values of these quantities were computed in terms of first story unknowns, every one of these nine unknowns being involved. Therefore, for Plate 13, for the first and all succeeding stories each of the column of values from C_1^A to Δ_0^d inclusive (would be C_2^A to Δ_1^d inclusive for first story solution)

would contain nine terms for each coefficient (ten for the numerical term z). The method of writing the values of these coefficients is illustrated for C_2^A thus: Let the coefficients of M_1^A, M_1^B, M_1^C, M_1^D, etc., under C_2^A of Plate 13 for the 0 story be now known as e^{C-A}, f^{C-A}, g^{C-A}, h^{C-A}, etc., and let the coefficients of M_2^A, M_2^B, M_2^C, etc., in the values of M_1^A, M_1^B, etc., in terms of second story unknowns only, for Plate 13 for the first story solution be known, as they were before for the 0 story solution, as e^{M-A}, f^{M-A}, g^{M-A}, e^{M-B}, f^{M-B}, g^{M-B}, etc. Then the coefficient of M_2^A in the values of C_2^A will be $e^{C-A}e^{M-A} + f^{C-A}e^{M-B} + g^{C-A}e^{M-C} + h^{C-A}e^{M-D} + l^{C-A}e^{S-A} + m^{C-A}$ $e^{S-B} + n^{C-A}e^{S-C} + g^{C-A}e^{V-B} + r^{C-A}e^{V-C}$.

In this manner the values of the coefficients of all the second story unknowns may be written for the values of the quantities C_2^A to Δ_1^d inclusive. Now the tables of values of C_3^A to Δ_2^d inclusive may be filled out; they will be as given on Plate 13 for C_2^A to Δ_1^d inclusive excepting for the change in the subscripts of the symbolic coefficients there given. Plate 13 as thus constructed for the first story solution will then be standard for all succeeding stories.

As no example of this general structure was calculated, due to a lack of time, the additional plates required for the revised plate 13 and for the revised coefficients α, β, γ, etc., as given above, for first and succeeding story solutions have been omitted. They may be readily constructed as described above by any one desiring to investigate such a structure. Now the work for each story is merely a repetition of that for the first story, and when the top story is reached it is evident that ω (Plate 12) will then consist of only the column z and the result of the tabulated calculations of Plate 13 for the top story gives numerical values of all top story unknowns. Substitution of these values thus found in connection with the tabulated coefficients of Plate 13 for the next lower story, gives the values of the unknowns for that story. This process is then continued until the 0 story is reached, when all unknowns will have become known. In the calculations of plates 11 and 12 a very nice check on the calculations may be kept by using Gauss's method as given in Chapter X of "Method of Least Squares," by Merriman.

Special Case of a Building of Only Two Columns to a Transverse Section.—The symbolic equations and values of the coefficients in

SYMBOLIC EQUATIONS FOR A TWO COLUMN CROSS SECTION.

Values of C-A.

$C^A_0 = 0$

$C^A_1 = a_0^{C-A} \cdot M^A_0 + i_0^{C-A} \cdot S^A_0$

$C^A_2 = a_1^{C-A} \cdot M^A_1 + i_1^{C-A} \cdot S^A_1 + C^A_1$

$C^A_3 = a_2^{C-A} \cdot M^A_2 + i_2^{C-A} \cdot S^A_2 + C^A_2$

Values of δ-A.

$\delta^A_0 = a_0^{\delta-A} \cdot M^A_0 + i_0^{\delta-A} \cdot S^A_0$

$\delta^A_1 = a_1^{\delta-A} \cdot M^A_1 + i_1^{\delta-A} \cdot S^A_1 + s_1^{\delta-A} \cdot C^A_1$

$\delta^A_2 = a_2^{\delta-A} \cdot M^A_2 + i_2^{\delta-A} \cdot S^A_2 + s_2^{\delta-A} \cdot C^A_2$

Values of H-a.

$H^a_0 = l_0^{H-a} \cdot S^A_1 + i_0^{H-a} \cdot S^A_0 + z_0^{H-a}$

$H^a_1 = l_1^{H-a} \cdot S^A_2 + i_1^{H-a} \cdot S^A_1 + z_1^{H-a}$

$H^a_2 = l_2^{H-a} \cdot S^A_3 + i_2^{H-a} \cdot S^A_2 + z_2^{H-a}$

Values of V-A.

$V^A_0 = a_0^{V-A} \cdot M^A_0 + b_0^{V-A} \cdot M^B_0 + z_0^{V-A}$

$V^A_1 = a_1^{V-A} \cdot M^A_1 + b_1^{V-A} \cdot M^B_1 + z_1^{V-A}$

$V^A_2 = a_2^{V-A} \cdot M^A_2 + b_2^{V-A} \cdot M^B_2 + z_2^{V-A}$

Values of α-A.

$\alpha^A_0 = a_0^{\alpha-A} \cdot M^A_0 + b_0^{\alpha-A} \cdot M^B_0 + z_0^{\alpha-A}$

$\alpha^A_1 = a_1^{\alpha-A} \cdot M^A_1 + b_1^{\alpha-A} \cdot M^B_1 + z_1^{\alpha-A}$

$\alpha^A_2 = a_2^{\alpha-A} \cdot M^A_2 + b_2^{\alpha-A} \cdot M^B_2 + z_2^{\alpha-A}$

Values of Δ-a.

$\Delta^a_0 = a_0^{\Delta-a} \cdot M^A_0 + b_0^{\Delta-a} \cdot M^B_0 + z_0^{\Delta-a}$

$\Delta^a_1 = a_1^{\Delta-a} \cdot M^A_1 + b_1^{\Delta-a} \cdot M^B_1 + z_1^{\Delta-a} + \Delta^a_0$

$\Delta^a_2 = a_2^{\Delta-a} \cdot M^A_2 + b_2^{\Delta-a} \cdot M^B_2 + z_2^{\Delta-a} + \Delta^a_1$

Values of R-a.

$R^a_0 = a_0^{R-a} \cdot M^A_0 + b_0^{R-a} \cdot M^B_0 + e_0^{R-a} \cdot M^A_1 + f_0^{R-a} \cdot M^B_1 + z_0^{R-a}$

$R^a_1 = a_1^{R-a} \cdot M^A_1 + b_1^{R-a} \cdot M^B_1 + e_1^{R-a} \cdot M^A_2 + f_1^{R-a} \cdot M^B_2 + z_1^{R-a}$

$R^a_2 = a_2^{R-a} \cdot M^A_2 + b_2^{R-a} \cdot M^B_2 + e_2^{R-a} \cdot M^A_3 + f_2^{R-a} \cdot M^B_3 + z_2^{R-a}$

Values of C-B.

$C^B_0 = 0$

$C^B_1 = b_0^{C-B} \cdot M^B_0 + i_0^{C-B} \cdot S^A_0 + z_0^{C-B}$

$C^B_2 = b_1^{C-B} \cdot M^B_1 + i_1^{C-B} \cdot S^A_1 + z_1^{C-B} + C^B_1$

$C^B_3 = b_2^{C-B} \cdot M^B_2 + i_2^{C-B} \cdot S^A_2 + z_2^{C-B} + C^B_2$

Values of δ-B.

$\delta^B_0 = b_0^{\delta-B} \cdot M^B_0 + i_0^{\delta-B} \cdot S^A_0 + z_0^{\delta-B}$

$\delta^B_1 = b_1^{\delta-B} \cdot M^B_1 + i_1^{\delta-B} \cdot S^A_1 + z_1^{\delta-B} + t_1^{\delta-B} \cdot C^B_1$

$\delta^B_2 = b_2^{\delta-B} \cdot M^B_2 + i_2^{\delta-B} \cdot S^A_2 + z_2^{\delta-B} + t_2^{\delta-B} \cdot C^B_2$

Values of λ-a.

$\lambda^a_0 = l_0^{\lambda-a} \cdot S^A_1 + i_0^{\lambda-a} \cdot S^A_0 + z_0^{\lambda-a}$

$\lambda^a_1 = l_1^{\lambda-a} \cdot S^A_2 + i_1^{\lambda-a} \cdot S^A_1 + z_1^{\lambda-a}$

$\lambda^a_2 = l_2^{\lambda-a} \cdot S^A_3 + i_2^{\lambda-a} \cdot S^A_2 + z_2^{\lambda-a}$

Values of V-B.

$V^B_0 = a_0^{V-B} \cdot M^A_0 + b_0^{V-B} \cdot M^B_0 + z_0^{V-B}$

$V^B_1 = a_1^{V-B} \cdot M^A_1 + b_1^{V-B} \cdot M^B_1 + z_1^{V-B}$

$V^B_2 = a_2^{V-B} \cdot M^A_2 + b_2^{V-B} \cdot M^B_2 + z_2^{V-B}$

Values of α-B.

$\alpha^B_0 = a_0^{\alpha-B} \cdot M^A_0 + b_0^{\alpha-B} \cdot M^B_0 + z_0^{\alpha-B}$

$\alpha^B_1 = a_1^{\alpha-B} \cdot M^A_1 + b_1^{\alpha-B} \cdot M^B_1 + z_1^{\alpha-B}$

$\alpha^B_2 = a_2^{\alpha-B} \cdot M^A_2 + b_2^{\alpha-B} \cdot M^B_2 + z_2^{\alpha-B}$

Values of Q-a.

$Q^a_0 = i_0^{Q-a} \cdot S^A_0 + l_0^{Q-a} \cdot S^A_1 + a_0^{Q-a} \cdot M^A_0 + e_0^{Q-a} \cdot M^A_1 + z_0^{Q-a}$

$Q^a_1 = i_1^{Q-a} \cdot S^A_1 + l_1^{Q-a} \cdot S^A_2 + a_1^{Q-a} \cdot M^A_1 + e_1^{Q-a} \cdot M^A_2 + z_1^{Q-a}$

$Q^a_2 = i_2^{Q-a} \cdot S^A_2 + l_2^{Q-a} \cdot S^A_3 + a_2^{Q-a} \cdot M^A_2 + e_2^{Q-a} \cdot M^A_3 + z_2^{Q-a}$

Equations A-a.

$a_0^{A-a} \cdot M^A_0 + b_0^{A-a} \cdot M^B_0 + i_0^{A-a} \cdot S^A_0 + l_0^{A-a} \cdot S^A_1 + z_0^{A-a} = 0$

$a_1^{A-a} \cdot M^A_1 + b_1^{A-a} \cdot M^B_1 + i_1^{A-a} \cdot S^A_1 + l_1^{A-a} \cdot S^A_2 + z_1^{A-a} + s_1^{A-a} \cdot C^A_1 + t_1^{A-a} \cdot C^B_1 + p_1^{A-a} \cdot S^A_0 = 0.$

$a_2^{A-a} \cdot M^A_2 + b_2^{A-a} \cdot M^B_2 + i_2^{A-a} \cdot S^A_2 + l_2^{A-a} \cdot S^A_3 + z_2^{A-a} + s_2^{A-a} \cdot C^A_2 + t_2^{A-a} \cdot C^B_2 + p_2^{A-a} \cdot S^A_1 = 0.$

Equations B-a.

$a_0^{B-a} \cdot M^A_0 + b_0^{B-a} \cdot M^B_0 + e_0^{B-a} \cdot M^A_1 + f_0^{B-a} \cdot M^B_1 + i_0^{B-a} \cdot S^A_0 + l_0^{B-a} \cdot S^A_1 + z_0^{B-a} = 0.$

$a_1^{B-a} \cdot M^A_1 + b_1^{B-a} \cdot M^B_1 + e_1^{B-a} \cdot M^A_2 + f_1^{B-a} \cdot M^B_2 + i_1^{B-a} \cdot S^A_1 + l_1^{B-a} \cdot S^A_2 + z_1^{B-a} + s_1^{B-a} \cdot C^A_1 + t_1^{B-a} \cdot C^B_1 = 0$

$a_2^{B-a} \cdot M^A_2 + b_2^{B-a} \cdot M^B_2 + e_2^{B-a} \cdot M^A_3 + f_2^{B-a} \cdot M^B_3 + i_2^{B-a} \cdot S^A_2 + l_2^{B-a} \cdot S^A_3 + z_2^{B-a} + s_2^{B-a} \cdot C^A_2 + t_2^{B-a} \cdot C^B_2 = 0$

Equations C-a.

$a_0^{C-a} \cdot M^A_0 + b_0^{C-a} \cdot M^B_0 + e_0^{C-a} \cdot M^A_1 + f_0^{C-A} \cdot M^B_1 + i_0^{C-a} \cdot S^A_0 + l_0^{C-a} \cdot S^A_1 + z_0^{C-a} = 0.$

$a_1^{C-a} \cdot M^A_1 + b_1^{C-a} \cdot M^B_1 + e_1^{C-a} \cdot M^A_2 + f_1^{C-a} \cdot M^B_2 + i_1^{C-a} \cdot S^A_1 + l_1^{C-a} \cdot S^A_2 + z_1^{C-a} + t_1^{C-a} \cdot C^B_1 + w_1^{C-a} \cdot \Delta^a_0 = 0$

$a_2^{C-a} \cdot M^A_2 + b_2^{C-a} \cdot M^B_2 + e_2^{C-a} \cdot M^A_3 + f_2^{C-a} \cdot M^B_3 + i_2^{C-a} \cdot S^A_2 + l_2^{C-a} \cdot S^A_3 + z_2^{C-a} + t_2^{C-a} \cdot C^B_2 + w_2^{C-a} \cdot \Delta^a_1 = 0$

PLATE 14.

VALUES OF THE COEFFICIENTS IN THE SYMBOLIC EQUATIONS FOR A TWO COLUMN CROSS SECTION.

	a_n	b_n	e_n	f_n	i_n	l_n	s_n	t_n	w_n	P_n	z_n
C-A	$C_n \div I_n^A$	0	0	0	$-C_n^2 \div 2I_n^A$	0	1	0	0	0	0
C-B	0	$C_n \div I_n^B$	0	0	$C_n^2 \div 2I_n^B$	0	0	1	0	0	$-C_n^2 \Sigma F_n \div 2I_n^B$
δ-A	$C_n^2 \div 2I_n^A$	0	0	0	$-C_n^3 \div 6I_n^A$	0	C_n	0	0	0	0
δ-B	0	$C_n^2 \div 2I_n^B$	0	0	$C_n^3 \div 6I_n^B$	0	0	C_n	0	0	$-C_n^3 \Sigma F_n \div 6I_n^B$
H-a	0	0	0	0	-1	1	0	0	0	0	F_n^A
λ-a	0	0	0	0	$-b \div A_n^a$	$b \div A_n^a$	0	0	0	0	$b z_n^{H-a} \div A_n^a$
V-A	$1 \div b$	$1 \div b$	0	0	0	0	0	0	0	0	$-X_n \div b$
V-B	$-1 \div b$	$-1 \div b$	0	0	0	0	0	0	0	0	$Y_n + X_n \div b$
α-A	$(C_n + \frac{1}{2}d_{n-1} + \frac{1}{2}d_n)a_n^{V-A} \div A_n^A$	$(C_n + \frac{1}{2}d_{n-1} + \frac{1}{2}d_n)b_n^{V-A} \div A_n^A$	0	0	0	0	0	0	0	0	$(C_n + \frac{1}{2}d_{n-1} + \frac{1}{2}d_n)z_n^{V-A} \div A_n^A$
α-B	$(C_n + \frac{1}{2}d_{n-1} + \frac{1}{2}d_n)a_n^{V-B} \div A_n^B$	$(C_n + \frac{1}{2}d_{n-1} + \frac{1}{2}d_n)b_n^{V-B} \div A_n^B$	0	0	0	0	0	0	0	0	$(C_n + \frac{1}{2}d_{n-1} + \frac{1}{2}d_n)z_n^{V-B} \div A_n^B$
Δ-a	$-a_n^{\alpha-A} + a_n^{\alpha-B}$	$-b_n^{\alpha-A} + b_n^{\alpha-B}$	0	0	0	0	0	0	1	0	$-z_n^{\alpha-A} + z_n^{\alpha-B}$
Q-a	$-1 \div I_n^a$	0	$1 \div I_n^a$	0	$(C_n + \frac{1}{2}d_n) \div I_n^a$	$d_n \div 2I_n^a$	0	0	0	0	$-P_n^A e_n^A \div I_n^a$
R-a	$a_n^{V-A} \div I_n^a$	$b_n^{V-A} \div I_n^a$	$-a_{n+1}^{V-A} \div I_n^a$	$-b_{n+1}^{V-A} \div I_n^a$	0	0	0	0	0	0	$(z_n^{V-A} - z_{n+1}^{V-A} - P_n^A) \div I_n^a$
A-a	$a_n^{\delta-A} + \frac{1}{2}d_n a_n^{C-A}$	$-b_n^{\delta-B} - \frac{1}{2}d_n b_n^{C-B}$	0	0	$i_n^{\delta-A} - i_n^{\delta-B} + \frac{1}{2}d_n(i_n^{C-A} - i_n^{C-B}) - i_n^{\lambda-a} + i_{n-1}^{\lambda-a}$	$-l_n^{\lambda-a}$	$s_n^{\delta-A} + \frac{1}{2}d_n s_n^{C-A} + \frac{1}{2}d_{n-1}$	$-t_n^{\delta-B} - \frac{1}{2}d_n t_n^{C-B} - \frac{1}{2}d_{n-1}$	0	$-b \div A_{n-1}^a$	$-z_n^{\lambda-a} + z_{n-1}^{\lambda-a} - z_n^{\delta-B} - \frac{1}{2}d_n z_n^{C-B}$
B-a	$(a_n^{Q-a} + b a_n^{R-a})b - \frac{1}{2}b^2 a_n^{R-a} - a_n^{C-A}$	$\frac{1}{2}b^2 b_n^{R-a} + b_n^{C-B}$	$(e_n^{Q-a} + b e_n^{R-a})b - \frac{1}{2}b^2 e_n^{R-a}$	$\frac{1}{2}b^2 f_n^{R-a}$	$b i_n^{Q-a} - i_n^{C-A} + i_n^{C-B}$	$b l_n^{Q-a}$	$-s_n^{C-A}$	t_n^{C-B}	0	0	$(z_n^{Q-a} + b z_n^{R-a})b - \frac{1}{2}b^2 z_n^{R-a} - b^3 w_n \div 6I_n^a + z_n^{C-B}$
C-a	$(a_n^{Q-a} + b a_n^{R-a})\frac{1}{2}b^2 - \frac{1}{6}b^3 a_n^{R-a} - a_n^{\Delta-a}$	$\frac{1}{3}b^3 b_n^{R-a} + b b_n^{C-B} - b_n^{\Delta-a}$	$(e_n^{Q-a} + b e_n^{R-a})\frac{1}{2}b^2 - \frac{1}{6}b^3 e_n^{R-a}$	$\frac{1}{3}b^3 f_n^{R-a}$	$\frac{1}{2}b^2 i_n^{Q-a} + b i_n^{C-B}$	$\frac{1}{2}b^2 l_n^{Q-a}$	0	$b t_n^{C-B}$	-1	0	$(z_n^{Q-a} + b z_n^{R-a})\frac{1}{2}b^2 - \frac{1}{6}b^3 z_n^{R-a} - b^4 w_n \div 8I_n^a + b z_n^{C-B} - z_n^{\Delta-a}$

The following are Rewritten Equations in which values of H^a have been substituted for values of S to agree with the Solution used in Chapters VI-VII-VIII-&IX. Values of Coefficients are as given in the Above Table excepting only those whose values are given in the Table to the Right.

$$C_{n+1}^A = a_n^{C-A} \cdot M_n^A + i_n^{C-A}(S_0^B - H_0^a - H_1^a \cdots - H_{n-1}^a) + C_n^A + z_n^{C-A}$$

$$C_{n+1}^B = b_n^{C-B} \cdot M_n^B + i_n^{C-B}(S_0^B - H_0^a - H_1^a \cdots - H_{n-1}^a) + C_n^B + z_n^{C-B}$$

$$\Delta_n^a = a_n^{\Delta-a} \cdot M_n^A + b_n^{\Delta-a} \cdot M_n^B + z_n^{\Delta-a} + \Delta_{n-1}^a$$

$$a_n^{A-a} \cdot M_n^A + b_n^{A-a} \cdot M_n^B + i_n^{A-a}(S_0^B - H_0^a - H_1^a \cdots - H_{n-1}^a) + l_n^{A-a} H_n^a + z_n^{A-a} + s_n^{A-a} C_n^A + t_n^{A-a} C_n^B + P_n^{A-a} H_{n-1}^a = 0$$

$$a_n^{B-a} \cdot M_n^A + b_n^{B-a} \cdot M_n^B + e_n^{B-a} \cdot M_{n+1}^A + f_n^{B-a} M_{n+1}^B + i_n^{B-a}(S_0^B - H_0^a - H_1^a \cdots - H_{n-1}^a) + l_n^{B-a} H_n^a + z_n^{B-a} + s_n^{B-a} C_n^A + t_n^{B-a} C_n^B = 0$$

$$a_n^{C-a} \cdot M_n^A + b_n^{C-a} \cdot M_n^B + e_n^{C-a} \cdot M_{n+1}^A + f_n^{C-a} M_{n+1}^B + i_n^{C-a}(S_0^B - H_0^a - H_1^a \cdots - H_{n-1}^a) + l_n^{C-a} H_n^a + z_n^{C-a} + w_n^{C-a} \Delta_{n-1}^a + t_n^{C-a} C_n^B = 0$$

Values of New Coefficients in Equations as Rewritten

	i_n	P_n	z_n
C-A	$-i_n^{C-A}$	0	$i_n^{C-A}(\Sigma F - F_0^A - F_1^A \cdots - F_{n-1}^A)$
C-B	$-i_n^{C-B}$	0	$z_n^{C-B} + i_n^{C-B}(\Sigma F - F_0^A - F_1^A \cdots - F_{n-1}^A)$
Δ-a	0	0	$z_n^{\Delta-a}$
A-a	$-(i_n^{A-a} + P_n^{A-a} + l_n^{A-a})$	$-P_n^{A-a}$	$z_n^{A-a} + (i_n^{A-a} + P_n^{A-a} + l_n^{A-a})(\Sigma F - F_0^A - F_1^A \cdots - F_{n-1}^A) - l_n^{A-a} F_n^A + P_n^{A-a} F_{n-1}^A$
B-a	$-(i_n^{B-a} + l_n^{B-a})$	0	$z_n^{B-a} + (i_n^{B-a} + l_n^{B-a})(\Sigma F - F_0^A - F_1^A \cdots - F_{n-1}^A) - l_n^{B-a} F_n^A$
C-a	$-(i_n^{C-a} + l_n^{C-a})$	0	$z_n^{C-a} + (i_n^{C-a} + l_n^{C-a})(\Sigma F - F_0^A - F_1^A \cdots - F_{n-1}^A) - l_n^{C-a} F_n^A$

PLATE 15.

these equations for this simple structure are readily written from those given for the general case. These equations are given on Plate 14 and the values of the coefficients are given on Plate 15. In applying this method in later chapters the quantities H^a and S_0^B were considered as unknowns in place of the quantities S^A in the formulae of Plate 14. This was due to the fact that these applications were made before the general case and formulae were attempted. The transformed equations necessary for the solution, as required by this modification are given in the lower left-hand corner of Plate 15 and the values of those coefficients affected by the transformation are given in the lower right-hand corner of the same plate. The transformation was effected by writing

$$S_n^A = [(\Sigma F - F_0^A - F_1^A - \cdots - F_{n-1}^A) - (S_0^B - H_0 - H_1 \\ - \cdots - H_{n-1})],$$

except in the term PS_{n-1}^A of equations A, in which was substituted

$$S_{n-1}^A = S_n^A - (H_{n-1}^A - F_{n-1}^A).$$

Now the equations may be further simplified as follows:

First. In equations A–a, B–a, and C–a, the last letter "a" of the exponents of the coefficients may be dropped.

Second. Dividing all coefficients in equations A–a by l, these equations may, for the nth story, be written

$$H_n = c_n^A M_n^A + l_n^A M_n^B + i_n^A (S_0^B H_0 - H_1 - \cdots - H_{n-1}) \\ + z_n^A + s_n^A C_n^A + t_n^A C_n^B + P_n^A H_{n-1}$$

in which the coefficients are, of course, different from the values already given, due to the operation just performed.

Third. Dividing all the coefficients of equations B–a by $b/4I_n^a$, and all those of equations C–a by $b^2/6I_n^a$ and then subtracting equations C–a from equations B–a, there results, for the nth story, the equation

$$M_{n+1}^A = a_n^B M_n^A + t_n^B M_n^B + i_n^B (S_0^B - H_0 - H_1 - \cdots - H_{n-1}) \\ + l_n^B H_n + z_n^B + s_n^B C_n^A + t_n^B C_n^B + w_n^B \Delta_{n-1},$$

in which the values of the coefficients are determined by the operation.

Fourth. Dividing all the coefficients of equations $B - a$ by $b/2I_n^a$, and all those of equations $C - a$ by $b^2/6I_n^a$ and then subtracting equations $B - a$ from equations $C - a$ there results, for the nth story, the equation

$$M_{n+1}^B = a_n^C M_n^A + b_n^C M_n^B + i_n^C(S_0^B - H_0 - H_1 - \cdots - H_{n-1}) + l_n^C H_n + z_n^C + s_n^C C_n^A + t_n^A C_n^B + w_n^C \Delta_{n-1},$$

in which the values of the coefficients are determined by the operation.

When the equations $A - a$, $B - a$ and $C - a$, and the coefficients occurring in these equations, are referred to in the following solution, the reference is to these revised equations and their coefficients.

The method used in solving these equations is now given on Plate 16, which, it is believed, explains itself. The Greek letter and other coefficients used on this plate have entirely different meanings from any they have had where previously used. The values of these coefficients are given on Plate 17. Plates 16 and 17 are for the first three stories only. For all succeeding stories the solution and coefficients may be written exactly the same as for the second story except for the subscripts, which must agree with the story for which the coefficients are written. When the last story of the building is reached the coefficients in the lines marked 9–10–11–13–14 and 15 may be omitted entirely and the two central columns of those in lines marked 6, 7, 8, and 12 may be omitted also; since the terms omitted are for quantities whose values are either already given in the previous story or they are terms or coefficients of terms which do not exist for the last story.

The solution for any structure, then, consists mainly of calculating the coefficients of Plate 17. For this purpose calculation sheets are ruled up in a form corresponding to Plate 17 and in each blank space the calculations for the coefficient found in the corresponding space of Plate 17 are inserted, these calculations being made by slide rule. Plate 17 must be kept constantly in view during calculations.

SOLUTION FOR A TWO COLUMN CROSS SECTION

From equation A_0^a there is obtained the expression	$S_0^B=\frac{1}{c_0}H_0-\frac{a_0}{c_0}M_0^A-\frac{b_0}{c_0}M_0^B-\frac{d_0}{c_0}$
Substituting this value of S_0^B in equation B_0^a there results	$M_0^A+A_0M_0^B=B_0M_1^A+C_0H_0+D_0$
Substituting this value of S_0^B in equation C_0^a there results	$M_0^A+A_0'M_0^B=B_0'M_1^B+C_0'H_0+D_0'$
Solving these two resulting equations there is obtained	$\left\{\begin{array}{l} M_0^A=\alpha_0H_0+\beta_0M_1^A+\gamma_0M_1^B+\delta_0 \\ M_0^B=\alpha_0'H_0+\beta_0'M_1^A+\gamma_0'M_1^B+\delta_0' \end{array}\right.$
Substituting these values of M_0^A & M_0^B in above value of S_0^B	$S_0^B=\alpha_0''H_0+\beta_0''M_1^A+\gamma_0''M_1^B+\delta_0''$
Subtracting H_0 from both sides of this equation	$S_0^B-H_0=(\alpha_0''-1)H_0+\beta_0''M_1^A+\gamma_0''M_1^B+\delta_0''$
Substituting above values of S_0^B, M_0^A & M_0^B in expression for C_1^A	$C_1^A=\alpha_0'''H_0+\beta_0'''M_1^A+\gamma_0'''M_1^B+\delta_0'''$
" " " " " " " " " " C_1^B	$C_1^B=\alpha_0^{IV}H_0+\beta_0^{IV}M_1^A+\gamma_0^{IV}M_1^B+\delta_0^{IV}$
" " " " " " " " " " Δ_0^a	$\Delta_0^a=\alpha_0^{V}H_0+\beta_0^{V}M_1^A+\gamma_0^{V}M_1^B+\delta_0^{V}$
Substituting values of $S_0^B-H_0$ & C_1^A in expression for C_2^A	$C_2^A=\theta_0H_0+\phi_0M_1^A+\psi_0M_1^B+\omega_0$
" " " " " C_1^B " " " C_2^B	$C_2^B=\theta_0'H_0+\phi_0'M_1^A+\psi_0'M_1^B+\omega_0'$
" " " Δ_0^a " " " Δ_1^a	$\Delta_1^a=\theta_0''H_0+\phi_0''M_1^A+\psi_0''M_1^B+\omega_0''$
" " " $S_0^B-H_0$, C_1^A & C_1^B in equation A_1^a there results	$H_0=\frac{1}{c_1}H_1-\frac{a_1}{c_1}M_1^A-\frac{b_1}{c_1}M_1^B-\frac{d_1}{c_1}$
" " " " " " & Δ_0^a " " B_1^a " "	$M_1^A+A_1M_1^B=B_1M_2^A+C_1H_1+D_1$
" " " " " " " " " " C_1^a " "	$M_1^A+A_1'M_1^B=B_1'M_2^B+C_1'H_1+D_1'$
Solving these two resulting equations there is obtained	$\left\{\begin{array}{l} M_1^A=\alpha_1H_1+\beta_1M_2^A+\gamma_1M_2^B+\delta_1 \\ M_1^B=\alpha_1'H_1+\beta_1'M_2^A+\gamma_1'M_2^B+\delta_1' \end{array}\right.$
Substituting these values of M_1^A & M_1^B in above value of H_0	$H_0=\alpha_1''H_1+\beta_1''M_2^A+\gamma_1''M_2^B+\delta_1''$
" " " " M_1^A, M_1^B & H_0 " " " " " C_2^A	$C_2^A=\alpha_1'''H_1+\beta_1'''M_2^A+\gamma_1'''M_2^B+\delta_1'''$
" " " " " " " " " " " " C_2^B	$C_2^B=\alpha_1^{IV}H_1+\beta_1^{IV}M_2^A+\gamma_1^{IV}M_2^B+\delta_1^{IV}$
" " " " " " " " " " " " Δ_1^a	$\Delta_1^a=\alpha_1^{V}H_1+\beta_1^{V}M_2^A+\gamma_1^{V}M_2^B+\delta_1^{V}$
" " " " " " " " " " " " $S_0^B-H_0$	$S_0^B-H_0=\alpha_1^{VI}H_1+\beta_1^{VI}M_2^A+\gamma_1^{VI}M_2^B+\delta_1^{VI}$
Subtracting H_1 from both sides of this equation	$S_0^B-H_0-H_1=(\alpha_1^{VI}-1)H_1+\beta_1^{VI}M_2^A+\gamma_1^{VI}M_2^B+\delta_1^{VI}$
Substituting above values of $S_0^B-H_0-H_1$ & C_2^A in expression for C_3^A	$C_3^A=\theta_1H_1+\phi_1M_2^A+\psi_1M_2^B+\omega_1$
" " " " " C_2^B " " " C_3^B	$C_3^B=\theta_1'H_1+\phi_1'M_2^A+\psi_1'M_2^B+\omega_1'$
" " " " Δ_1^a " " " Δ_2^a	$\Delta_2^a=\theta_1''H_1+\phi_1''M_2^A+\psi_1''M_2^B+\omega_1''$
" " " $S_0^B-H_0-H_1$, C_2^A & C_2^B in equation A_2^a gives	$H_1=\frac{1}{c_2}H_2-\frac{a_2}{c_2}M_2^A-\frac{b_2}{c_2}M_2^B-\frac{d_2}{c_2}$
" " " " " " & Δ_1^a " B_2^a "	$M_2^A+A_2M_2^B=B_2M_3^A+C_2H_2+D_2$
" " " " " " " " " C_2^a "	$M_2^A+A_2'M_2^B=B_2'M_3^B+C_2'H_2+D_2'$
Solving these two resulting equations there is obtained	$\left\{\begin{array}{l} M_2^A=\alpha_2H_2+\beta_2M_3^A+\gamma_2M_3^B+\delta_2 \\ M_2^B=\alpha_2'H_2+\beta_2'M_3^A+\gamma_2'M_3^B+\delta_2' \end{array}\right.$
Substituting these values of M_2^A & M_2^B in above value of H_1	$H_1=\alpha_2''H_2+\beta_2''M_3^A+\gamma_2''M_3^B+\delta_2''$
" " " " M_2^A, M_2^B & H_1 " " " " C_3^A	$C_3^A=\alpha_2'''H_2+\beta_2'''M_3^A+\gamma_2'''M_3^B+\delta_2'''$
" " " " " " " " " " " C_3^B	$C_3^B=\alpha_2^{IV}H_2+\beta_2^{IV}M_3^A+\gamma_2^{IV}M_3^B+\delta_2^{IV}$
" " " " " " " " " " " Δ_2^a	$\Delta_2^a=\alpha_2^{V}H_2+\beta_2^{V}M_3^A+\gamma_2^{V}M_3^B+\delta_2^{V}$
" " " " " " " " " " " $S_0^B-H_0-H_1$	$S_0^B-H_0-H_1=\alpha_2^{VI}H_2+\beta_2^{VI}M_3^A+\gamma_2^{VI}M_3^B+\delta_2^{VI}$
Subtracting H_2 from both sides of this equation	$S_0^B-H_0-H_1-H_2=(\alpha_2^{VI}-1)H_2+\beta_2^{VI}M_3^A+\gamma_2^{VI}M_3^B+\delta_2^{VI}$
Substituting above values of $S_0^B-H_0-H_1-H_2$ & C_3^A in expression for C_4^A	$C_4^A=\theta_2H_2+\phi_2M_3^A+\psi_2M_3^B+\omega_2$
" " " " " C_3^B " " C_4^B	$C_4^B=\theta_2'H_2+\phi_2'M_3^A+\psi_2'M_3^B+\omega_2'$
" " " " Δ_2^a " " " Δ_3^a	$\Delta_3^a=\theta_2''H_2+\phi_2''M_3^A+\psi_2''M_3^B+\omega_2''$

PLATE 16.

TABULATED VALUES OF THE COEFFICIENTS IN THE SOLUTION FOR THE O STORY

$c_0 = i_0^A$	$a_0 = a_0^A$	$b_0 = b_0^A$	$d_0 = z_0^A$
$A_0 = \frac{i_0^A b_0^B - i_0^B b_0^A}{i_0^A a_0^B - i_0^B a_0^A}$	$B_0 = \frac{i_0^A}{i_0^A a_0^B - i_0^B a_0^A}$	$C_0 = \frac{-i_0^A i_0^B - i_0^B}{i_0^A a_0^B - i_0^B a_0^A}$	$D_0 = \frac{-i_0^A z_0^B + i_0^B z_0^A}{i_0^A a_0^B - i_0^B a_0^A}$
$A_0' = \frac{i_0^A b_0^C - i_0^C b_0^A}{i_0^A a_0^C - i_0^C a_0^A}$	$B_0' = \frac{i_0^A}{i_0^A a_0^C - i_0^C a_0^A}$	$C_0' = \frac{-i_0^A i_0^C - i_0^C}{i_0^A a_0^C - i_0^C a_0^A}$	$D_0' = \frac{-i_0^A z_0^C + i_0^C z_0^A}{i_0^A a_0^C - i_0^C a_0^A}$
$\alpha_0 = \frac{A_0 C_0' - A_0' C_0}{A_0 - A_0'}$	$\beta_0 = -\frac{A_0' B_0}{A_0 - A_0'}$	$\gamma_0 = \frac{A_0 B_0'}{A_0 - A_0'}$	$\delta_0 = \frac{A_0 D_0' - A_0' D_0}{A_0 - A_0'}$
$\alpha_0' = \frac{C_0 - C_0'}{A_0 - A_0'}$	$\beta_0' = \frac{B_0}{A_0 - A_0'}$	$\gamma_0' = -\frac{B_0'}{A_0 - A_0'}$	$\delta_0' = \frac{D_0 - D_0'}{A_0 - A_0'}$
$\alpha_0'' = \frac{1}{c_0} - \frac{a_0 \alpha_0}{c_0} - \frac{b_0 \alpha_0'}{c_0}$	$\beta_0'' = -\frac{a_0 \beta_0}{c_0} - \frac{b_0 \beta_0'}{c_0}$	$\gamma_0'' = -\frac{a_0 \gamma_0}{c_0} - \frac{b_0 \gamma_0'}{c_0}$	$\delta_0'' = -\frac{d_0}{c_0} - \frac{a_0 \delta_0}{c_0} - \frac{b_0 \delta_0'}{c_0}$
$\alpha_0''' = a_0^{C-A} \alpha_0 + i_0^{C-A} \alpha_0''$	$\beta_0''' = a_0^{C-A} \beta_0 + i_0^{C-A} \beta_0''$	$\gamma_0''' = a_0^{C-A} \gamma_0 + i_0^{C-A} \gamma_0''$	$\delta_0''' = z_0^{C-A} + a_0^{C-A} \delta_0 + i_0^{C-A} \delta_0''$
$\alpha_0^{IV} = b_0^{C-B} \alpha_0' + i_0^{C-B} \alpha_0''$	$\beta_0^{IV} = b_0^{C-B} \beta_0' + i_0^{C-B} \beta_0''$	$\gamma_0^{IV} = b_0^{C-B} \gamma_0' + i_0^{C-B} \gamma_0''$	$\delta_0^{IV} = z_0^{C-B} + b_0^{C-B} \delta_0' + i_0^{C-B} \delta_0''$
$\alpha_0^{V} = a_0^{\Delta-a} \alpha_0 + b_0^{\Delta-a} \alpha_0'$	$\beta_0^{V} = a_0^{\Delta-a} \beta_0 + b_0^{\Delta-a} \beta_0'$	$\gamma_0^{V} = a_0^{\Delta-a} \gamma_0 + b_0^{\Delta-a} \gamma_0'$	$\delta_0^{V} = z_0^{\Delta-a} + a_0^{\Delta-a} \delta_0 + b_0^{\Delta-a} \delta_0'$
$\theta_0 = \alpha_0''' + i_1^{C-A}(\alpha_0'' - 1)$	$\phi_0 = a_1^{C-A} + \beta_0''' + i_1^{C-A} \beta_0''$	$\psi_0 = \gamma_0''' + i_1^{C-A} \gamma_0''$	$\omega_0 = z_1^{C-A} + \delta_0''' + i_1^{C-A} \delta_0''$
$\theta_0' = \alpha_0^{IV} + i_1^{C-B}(\alpha_0'' - 1)$	$\phi_0' = \beta_0^{IV} + i_1^{C-B} \beta_0''$	$\psi_0' = \gamma_0^{IV} + i_1^{C-B} \gamma_0'' + b_1^{C-B}$	$\omega_0' = z_1^{C-B} + \delta_0^{IV} + i_1^{C-B} \delta_0''$
$\theta_0'' = \alpha_0^{V}$	$\phi_0'' = a_1^{\Delta-a} + \beta_0^{V}$	$\psi_0'' = b_1^{\Delta-a} + \gamma_0^{V}$	$\omega_0'' = z_1^{\Delta-a} + \delta_0^{V}$

TABULATED VALUES OF THE COEFFICIENTS IN THE SOLUTION FOR THE 1ST STORY

$c_1 = i_1^A(\alpha_0''-1) + s_1^A \alpha_0''' + t_1^A \alpha_0^{IV} + p_1^A$	$a_1 = a_1^A + i_1^A \beta_0'' + s_1^A \beta_0''' + t_1^A \beta_0^{IV}$	$b_1 = b_1^A + i_1^A \gamma_0'' + s_1^A \gamma_0''' + t_1^A \gamma_0^{IV}$	$d_1 = z_1^A + i_1^A \delta_0'' + s_1^A \delta_0''' + t_1^A \delta_0^{IV}$
$i_1 = i_1^B(\alpha_0''-1) + s_1^B \alpha_0''' + t_1^B \alpha_0^{IV} + w_1^B \alpha_0^{V}$	$g_1 = a_1^B + i_1^B \beta_0'' + s_1^B \beta_0''' + t_1^B \beta_0^{IV} + w_1^B \beta_0^{V}$	$h_1 = b_1^B + i_1^B \gamma_0'' + s_1^B \gamma_0''' + t_1^B \gamma_0^{IV} + w_1^B \gamma_0^{V}$	$k_1 = -z_1^B - i_1^B \delta_0'' - s_1^B \delta_0''' - t_1^B \delta_0^{IV} - w_1^B \delta_0^{V}$
$p_1 = i_1^C(\alpha_0''-1) + s_1^C \alpha_0''' + t_1^C \alpha_0^{IV} + w_1^C \alpha_0^{V}$	$n_1 = a_1^C + i_1^C \beta_0'' + s_1^C \beta_0''' + t_1^C \beta_0^{IV} + w_1^C \beta_0^{V}$	$o_1 = b_1^C + i_1^C \gamma_0'' + s_1^C \gamma_0''' + t_1^C \gamma_0^{IV} + w_1^C \gamma_0^{V}$	$q_1 = -z_1^C - i_1^C \delta_0'' - s_1^C \delta_0''' - t_1^C \delta_0^{IV} - w_1^C \delta_0^{V}$
$A_1 = \frac{c_1 h_1 - i_1 b_1}{c_1 g_1 - i_1 a_1}$	$B_1 = \frac{c_1}{c_1 g_1 - i_1 a_1}$	$C_1 = \frac{-c_1 i_1^B - i_1}{c_1 g_1 - i_1 a_1}$	$D_1 = \frac{c_1 k_1 + i_1 d_1}{c_1 g_1 - i_1 a_1}$
$A_1' = \frac{c_1 o_1 - p_1 b_1}{c_1 n_1 - p_1 a_1}$	$B_1' = \frac{c_1}{c_1 n_1 - p_1 a_1}$	$C_1' = \frac{-c_1 i_1^C - p_1}{c_1 n_1 - p_1 a_1}$	$D_1' = \frac{c_1 q_1 + p_1 d_1}{c_1 n_1 - p_1 a_1}$
$\alpha_1 = \frac{A_1 C_1' - A_1' C_1}{A_1 - A_1'}$	$\beta_1 = -\frac{A_1' B_1}{A_1 - A_1'}$	$\gamma_1 = \frac{A_1 B_1'}{A_1 - A_1'}$	$\delta_1 = \frac{A_1 D_1' - A_1' D_1}{A_1 - A_1'}$
$\alpha_1' = \frac{C_1 - C_1'}{A_1 - A_1'}$	$\beta_1' = \frac{B_1}{A_1 - A_1'}$	$\gamma_1' = -\frac{B_1'}{A_1 - A_1'}$	$\delta_1' = \frac{D_1 - D_1'}{A_1 - A_1'}$
$\alpha_1'' = \frac{1}{c_1} - \frac{a_1 \alpha_1}{c_1} - \frac{b_1 \alpha_1'}{c_1}$	$\beta_1'' = -\frac{a_1 \beta_1}{c_1} - \frac{b_1 \beta_1'}{c_1}$	$\gamma_1'' = -\frac{a_1 \gamma_1}{c_1} - \frac{b_1 \gamma_1'}{c_1}$	$\delta_1'' = -\frac{d_1}{c_1} - \frac{a_1 \delta_1}{c_1} - \frac{b_1 \delta_1'}{c_1}$
$\alpha_1''' = \theta_0 \alpha_1'' + \phi_0 \alpha_1 + \psi_0 \alpha_1'$	$\beta_1''' = \theta_0 \beta_1'' + \phi_0 \beta_1 + \psi_0 \beta_1'$	$\gamma_1''' = \theta_0 \gamma_1'' + \phi_0 \gamma_1 + \psi_0 \gamma_1'$	$\delta_1''' = \omega_0 + \theta_0 \delta_1'' + \phi_0 \delta_1 + \psi_0 \delta_1'$
$\alpha_1^{IV} = \theta_0' \alpha_1'' + \phi_0' \alpha_1 + \psi_0' \alpha_1'$	$\beta_1^{IV} = \theta_0' \beta_1'' + \phi_0' \beta_1 + \psi_0' \beta_1'$	$\gamma_1^{IV} = \theta_0' \gamma_1'' + \phi_0' \gamma_1 + \psi_0' \gamma_1'$	$\delta_1^{IV} = \omega_0' + \theta_0' \delta_1'' + \phi_0' \delta_1 + \psi_0' \delta_1'$
$\alpha_1^{V} = \theta_0'' \alpha_1'' + \phi_0'' \alpha_1 + \psi_0'' \alpha_1'$	$\beta_1^{V} = \theta_0'' \beta_1'' + \phi_0'' \beta_1 + \psi_0'' \beta_1'$	$\gamma_1^{V} = \theta_0'' \gamma_1'' + \phi_0'' \gamma_1 + \psi_0'' \gamma_1'$	$\delta_1^{V} = \omega_0'' + \theta_0'' \delta_1'' + \phi_0'' \delta_1 + \psi_0'' \delta_1'$
$\alpha_1^{VI} = (\alpha_0''-1)\alpha_1'' + \beta_0'' \alpha_1 + \gamma_0'' \alpha_1'$	$\beta_1^{VI} = (\alpha_0''-1)\beta_1'' + \beta_0'' \beta_1 + \gamma_0'' \beta_1'$	$\gamma_1^{VI} = (\alpha_0''-1)\gamma_1'' + \beta_0'' \gamma_1 + \gamma_0'' \gamma_1'$	$\delta_1^{VI} = \delta_0'' + (\alpha_0''-1)\delta_1'' + \beta_0'' \delta_1 + \gamma_0'' \delta_1'$
$\theta_1 = \alpha_1''' + i_2^{C-A}(\alpha_1^{VI} - 1)$	$\phi_1 = a_2^{C-A} + \beta_1''' + i_2^{C-A} \beta_1^{VI}$	$\psi_1 = \gamma_1''' + i_2^{C-A} \gamma_1^{VI}$	$\omega_1 = z_2^{C-A} + \delta_1''' + i_2^{C-A} \delta_1^{VI}$
$\theta_1' = \alpha_1^{IV} + i_2^{C-B}(\alpha_1^{VI} - 1)$	$\phi_1' = \beta_1^{IV} + i_2^{C-B} \beta_1^{VI}$	$\psi_1' = b_2^{C-B} + \gamma_1^{IV} + i_2^{C-B} \gamma_1^{VI}$	$\omega_1' = z_2^{C-B} + \delta_1^{IV} + i_2^{C-B} \delta_1^{VI}$
$\theta_1'' = \alpha_1^{V}$	$\phi_1'' = a_2^{\Delta-a} + \beta_1^{V}$	$\psi_1'' = b_2^{\Delta-a} + \gamma_1^{V}$	$\omega_1'' = z_2^{\Delta-a} + \delta_1^{V}$

TABULATED VALUES OF THE COEFFICIENTS IN THE SOLUTION FOR THE 2ND STORY

1	$c_2 = i_2^A(\alpha_1^{VI}-1) + s_2^A \alpha_1''' + t_2^A \alpha_1^{IV} + p_2^A$	$a_2 = a_2^A + i_2^A \beta_1^{VI} + s_2^A \beta_1''' + t_2^A \beta_1^{IV}$	$b_2 = b_2^A + i_2^A \gamma_1^{VI} + s_2^A \gamma_1''' + t_2^A \gamma_1^{IV}$	$d_2 = z_2^A + i_2^A \delta_1^{VI} + s_2^A \delta_1''' + t_2^A \delta_1^{IV}$	1
2	$i_2 = i_2^B(\alpha_1^{VI}-1) + s_2^B \alpha_1''' + t_2^B \alpha_1^{IV} + w_2^B \alpha_1^{V}$	$g_2 = a_2^B + i_2^B \beta_1^{VI} + s_2^B \beta_1''' + t_2^B \beta_1^{IV} + w_2^B \beta_1^{V}$	$h_2 = b_2^B + i_2^B \gamma_1^{VI} + s_2^B \gamma_1''' + t_2^B \gamma_1^{IV} + w_2^B \gamma_1^{V}$	$k_2 = -z_2^B - i_2^B \delta_1^{VI} - s_2^B \delta_1''' - t_2^B \delta_1^{IV} - w_2^B \delta_1^{V}$	2
3	$p_2 = i_2^C(\alpha_1^{VI}-1) + s_2^C \alpha_1''' + t_2^C \alpha_1^{IV} + w_2^C \alpha_1^{V}$	$n_2 = a_2^C + i_2^C \beta_1^{VI} + s_2^C \beta_1''' + t_2^C \beta_1^{IV} + w_2^C \beta_1^{V}$	$o_2 = b_2^C + i_2^C \gamma_1^{VI} + s_2^C \gamma_1''' + t_2^C \gamma_1^{IV} + w_2^C \gamma_1^{V}$	$q_2 = -z_2^C - i_2^C \delta_1^{VI} - s_2^C \delta_1''' - t_2^C \delta_1^{IV} - w_2^C \delta_1^{V}$	3
4	$A_2 = \frac{c_2 h_2 - i_2 b_2}{c_2 g_2 - i_2 a_2}$	$B_2 = \frac{c_2}{c_2 g_2 - i_2 a_2}$	$C_2 = \frac{-c_2 i_2^B - i_2}{c_2 g_2 - i_2 a_2}$	$D_2 = \frac{c_2 k_2 + i_2 d_2}{c_2 g_2 - i_2 a_2}$	4
5	$A_2' = \frac{c_2 o_2 - p_2 b_2}{c_2 n_2 - p_2 a_2}$	$B_2' = \frac{c_2}{c_2 n_2 - p_2 a_2}$	$C_2' = \frac{-c_2 i_2^C - p_2}{c_2 n_2 - p_2 a_2}$	$D_2' = \frac{c_2 q_2 - p_2 d_2}{c_2 n_2 - p_2 a_2}$	5
6	$\alpha_2 = \frac{A_2 C_2' - A_2' C_2}{A_2 - A_2'}$	$\beta_2 = -\frac{A_2' B_2}{A_2 - A_2'}$	$\gamma_2 = \frac{A_2 B_2'}{A_2 - A_2'}$	$\delta_2 = \frac{A_2 D_2' - A_2' D_2}{A_2 - A_2'}$	6
7	$\alpha_2' = \frac{C_2 - C_2'}{A_2 - A_2'}$	$\beta_2' = \frac{B_2}{A_2 - A_2'}$	$\gamma_2' = -\frac{B_2'}{A_2 - A_2'}$	$\delta_2' = \frac{D_2 - D_2'}{A_2 - A_2'}$	7
8	$\alpha_2'' = \frac{1}{c_2} - \frac{a_2 \alpha_2}{c_2} - \frac{b_2 \alpha_2'}{c_2}$	$\beta_2'' = -\frac{a_2 \beta_2}{c_2} - \frac{b_2 \beta_2'}{c_2}$	$\gamma_2'' = -\frac{a_2 \gamma_2}{c_2} - \frac{b_2 \gamma_2'}{c_2}$	$\delta_2'' = -\frac{d_2}{c_2} - \frac{a_2 \delta_2}{c_2} - \frac{b_2 \delta_2'}{c_2}$	8
9	$\alpha_2''' = \theta_1 \alpha_2'' + \phi_1 \alpha_2 + \psi_1 \alpha_2'$	$\beta_2''' = \theta_1 \beta_2'' + \phi_1 \beta_2 + \psi_1 \beta_2'$	$\gamma_2''' = \theta_1 \gamma_2'' + \phi_1 \gamma_2 + \psi_1 \gamma_2'$	$\delta_2''' = \omega_1 + \theta_1 \delta_2'' + \phi_1 \delta_2 + \psi_1 \delta_2'$	9
10	$\alpha_2^{IV} = \theta_1' \alpha_2'' + \phi_1' \alpha_2 + \psi_1' \alpha_2'$	$\beta_2^{IV} = \theta_1' \beta_2'' + \phi_1' \beta_2 + \psi_1' \beta_2'$	$\gamma_2^{IV} = \theta_1' \gamma_2'' + \phi_1' \gamma_2 + \psi_1' \gamma_2'$	$\delta_2^{IV} = \omega_1' + \theta_1' \delta_2'' + \phi_1' \delta_2 + \psi_1' \delta_2'$	10
11	$\alpha_2^{V} = \theta_1'' \alpha_2'' + \phi_1'' \alpha_2 + \psi_1'' \alpha_2'$	$\beta_2^{V} = \theta_1'' \beta_2'' + \phi_1'' \beta_2 + \psi_1'' \beta_2'$	$\gamma_2^{V} = \theta_1'' \gamma_2'' + \phi_1'' \gamma_2 + \psi_1'' \gamma_2'$	$\delta_2^{V} = \omega_1'' + \theta_1'' \delta_2'' + \phi_1'' \delta_2 + \psi_1'' \delta_2'$	11
12	$\alpha_2^{VI} = (\alpha_1^{VI}-1)\alpha_2'' + \beta_1^{VI} \alpha_2 + \gamma_1^{VI} \alpha_2'$	$\beta_2^{VI} = (\alpha_1^{VI}-1)\beta_2'' + \beta_1^{VI} \beta_2 + \gamma_1^{VI} \beta_2'$	$\gamma_2^{VI} = (\alpha_1^{VI}-1)\gamma_2'' + \beta_1^{VI} \gamma_2 + \gamma_1^{VI} \gamma_2'$	$\delta_2^{VI} = \delta_1^{VI} + (\alpha_1^{VI}-1)\delta_2'' + \beta_1^{VI} \delta_2 + \gamma_1^{VI} \delta_2'$	12
13	$\theta_2 = \alpha_2''' + i_3^{C-A}(\alpha_2^{VI} - 1)$	$\phi_2 = a_3^{C-A} + \beta_2''' + i_3^{C-A} \beta_2^{VI}$	$\psi_2 = \gamma_2''' + i_3^{C-A} \gamma_2^{VI}$	$\omega_2 = z_3^{C-A} + \delta_2''' + i_3^{C-A} \delta_2^{VI}$	13
14	$\theta_2' = \alpha_2^{IV} + i_3^{C-B}(\alpha_2^{VI} - 1)$	$\phi_2' = \beta_2^{IV} + i_3^{C-B} \beta_2^{VI}$	$\psi_2' = b_3^{C-B} + \gamma_2^{IV} + i_3^{C-B} \gamma_2^{VI}$	$\omega_2' = z_3^{C-B} + \delta_2^{IV} + i_3^{C-B} \delta_2^{VI}$	14
15	$\theta_2'' = \alpha_2^{V}$	$\phi_2'' = a_3^{\Delta-a} + \beta_2^{V}$	$\psi_2'' = b_3^{\Delta-a} + \gamma_2^{V}$	$\omega_2'' = z_3^{\Delta-a} + \delta_2^{V}$	15

PLATE 17.

Writing out the equation represented by the coefficients in line 12 of the last story gives

$$S_0^B - H_0 - H_1 - \cdots - H_{n-1} = \alpha_n^{\text{vi}} H_n + \beta_n^{\text{vi}} M_{n+1}^A + \gamma_n^{\text{vi}} M_{n+1}^B + \delta_n^{\text{vi}},$$

where the nth is the last story; but there are no terms M_{n+1}^A and M_{n+1}^B, hence the coefficients β_n^{vi} and γ_n^{vi} may be omitted as mentioned above and the equation may be written

$$S_0^B - H_0 - H_1 - \cdots - H_{n-1} = \alpha_n^{\text{vi}} H_n + \delta_n^{\text{vi}}.$$

Now, from the principle that the sum of the horizontal forces acting on a section must equal zero, a vertical section being taken so as to cut through all the floor girders of the structure and, the portion of the building on the right of this section being considered,

$$S_0^B - H_0 - H_1 - \cdots - H_{n+1} = H_n - \Sigma F^B.$$

Hence, making this substitution in the equation above

$$H_n(1 - \alpha_n^{\text{vi}}) = \delta_n^{\text{vi}} + \Sigma F^B,$$

which gives the value of H_n. Now, starting at the bottom of the tabular computations and using this value of H_n, find, in the last story, the values of M_n^A and M_n^B. Then, using these values of H_n, M_n^A and M_n^B, in the next to the last story deduce the values of all quantities whose coefficients have been tabulated for this story. Again, using the values thus found for H_{n-1} M_{n-1}^A, and M_{n-1}^B evaluate similarly the unknowns of the story below. This operation may be repeated until the unknowns for all stories have been evaluated.

Checks.—The following checks may now be applied.

First. After all values of H and S_0^B are computed see if the condition given above, *i. e.*,

$$S_0^B - H_0 - H_1 - \cdots - H_{n-1} = H_n - \Sigma F^B,$$

is satisfied. This condition may be satisfied and yet all results may be very far from the true solution.

Second. The conditions forming, when expressed symbolically, equations A are simple geometrical ones and must be fulfilled for *every story.*

This is indeed a very delicate check and, when satisfied for *all* stories, assures that the calculations for all quantities are free from error, with the possible exception of the quantity Δ, the coefficients for which are so small.

Third. When there are a large number of stories it will be very advisable to use a check calculation in connection with Plate 17, somewhat similar to that used by Gauss in solution of normal equations. This will enable the calculator to check his work at each story as it progresses.

The check on the values of H is given first because, for a few stories only, it is naturally the first check available. The second is the real check of them all. If desired, the values of C^A, and C^B may be evaluated from their original expressions using the values of H, M^A, and M^B found in the solution. Likewise any other condition of the problem may be tested, but if the second check is fully satisfied these extra checks are unnecessary. It is well to note that all the calculations necessary may be quite accurately made on a Thacher slide rule, for the most part without any scratch figures not shown in the blanks. Calculations for various loadings differ only in the fourth column of Plate 17.

CHAPTER IV.

A STUDY OF THE EFFECT OF ECCENTRIC LOADING ON COLUMNS.

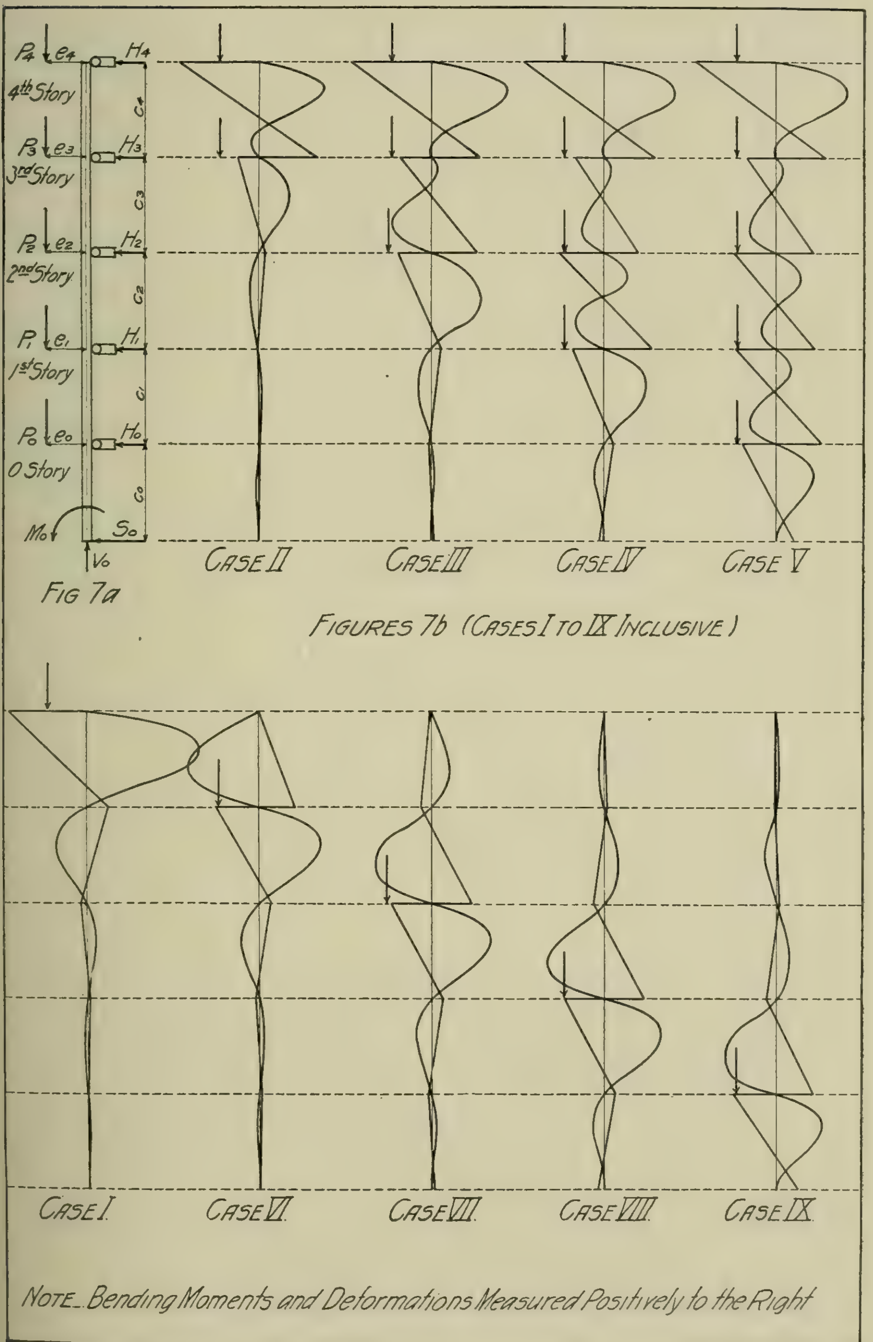
This little chapter is introduced in order, first, to present the results arrived at by the late Professor A. H. Heller in "Stresses in Structures" in what is considered a more comprehensive manner, and, second, to give a simple application of the general systematic method of solving the stresses in a structure composed of several stories. No new conclusions are pointed out here and the reader is referred to Chapter VII, IX, and XVI for original calculations and conclusions.

The equations of the elastic line for any section of the column shown in Fig. 7, *a*, will, in general, be the same as those given on page 39 of Chapter III. (Compare Fig. 6, *b*.) These equations are

$$E\frac{d^2y}{dx^2} = \frac{M}{I} - \frac{S}{I}x; \quad E\frac{dy}{dx} = \frac{M}{I}x - \frac{S}{2I}x^2 + K;$$

$$Ey = \frac{M}{2I}x^2 - \frac{S}{6I}x^3 + Kx + K'.$$

The column taken as an illustration for this chapter is a five story one, Fig. 7, *a*, with eccentric loads on the same side of the column at every floor. The column is considered as of constant moment of inertia from top to bottom. This column may be regarded as one of two symmetrical columns of a two column cross section symmetrically loaded, the two columns being joined by shallow girders which are considered as pin connected. The arrows, Fig. 7, *a*, indicate the assumed direction of the axial stresses in the girders; any stress coming out negative in the solution must act in a direction opposite to that shown. Assuming that the girders do not change in length under stress, a vertical line through the foot of the column will pass through all the intersections of girders with the column, *i. e.*, $\delta = 0$, for each column section. Also assume the column to be held vertically at the anchorage. Consider the column section for each story as having a separate origin


P4 e4 H4
4th Story
c4
P3 e3 H3
3rd Story
c3
P2 e2 H2
2nd Story
c2
P1 e1 H1
1st Story
c1
P0 e0 H0
0 Story
c0
M0 S0
V0
FIG 7a
CASE II
CASE III
CASE IV
CASE V
FIGURES 7b (CASES I TO IX INCLUSIVE)
CASE I.
CASE VI.
CASE VII.
CASE VIII.
CASE IX.
NOTE_ Bending Moments and Deformations Measured Positively to the Right

of coordinates at the foot of the column section. Then, as in Chapter III, $K = C$, and $K' = 0$ and the column slopes and deflections may be written as follows:

E_x Column Slopes.	E_x Column Deflections.
$C_0 = 0,$	$\delta_0 = \dfrac{M_0c_0^2}{2I_0} - \dfrac{S_0c_0^3}{6I_0} = 0,$
$C_1 = \dfrac{M_0c_0}{I_0} - \dfrac{S_0c_0^2}{2I_0},$	$\delta_1 = \dfrac{M_1c_1^2}{2I_1} - \dfrac{S_1c_1^3}{6I_1} + C_1c_1 = 0,$
$C_2 = \dfrac{M_1c_1}{I_1} - \dfrac{S_1c_1^2}{2I_1} + C_1,$	$\delta_2 = \dfrac{M_2c_2^2}{2I_2} - \dfrac{S_2c_2^3}{6I_2} + C_2c_2 = 0.$
$C_3 = \dfrac{M_2c_2}{I_2} - \dfrac{S_2c_2^2}{2I_2} + C_2.$	

The column bending moment existing just above the top of the nth story is M_{n+1} which must equal $- S_nc_n + M_n + P_ne_n$. These equations may be written for all values of n as follows:

$$M_n - S_nc_n = M_{n+1} - P_ne_n,$$
$$M_0 - S_0c_0 = M_1 - P_0e_0,$$
$$M_1 - S_1c_1 = M_2 - P_1e_1,$$
$$M_2 - S_2c_2 = M_3 - P_2e_2.$$

Now, rewriting the three sets of equations above symbolically using coefficients corresponding to Chapter III as nearly as may be,

Equations C.	Equations δ.
$C_0 = 0,$	$a_0^\delta M_0 + i_0^\delta S_0 = 0,$
$C_1 = a_0^C M_0 + i_0^C S_0,$	$a_1^\delta M_1 + i_1^\delta S_1 + s_1^\delta C_1 = 0,$
$C_2 = a_1^C M_1 + i_1^C S_1 + C_1,$	$a_2^\delta M_2 + i_2^\delta S_2 + s_2^\delta C_2 = 0.$
$C_3 = a_2^C M_2 + i_2^C S_2 + C_2.$	

Equations M.

$$M_0 + i_0^M S_0 = M_1 + z_0^M,$$
$$M_1 + i_1^M S_1 = M_2 + z_1^M,$$
$$M_2 + i_2^M S_2 = M_3 + z_2^M.$$

The values of the coefficients in the above equations are:

Equation.	a_n.	i_n,	s_n.	z_n.
C	$C_n \div I_n$	$-C_n^2 \div 2I_n$	1.0	0
δ	$C_n^2 \div 2I_n$	$-C_n^3 \div 6I_n$	C_n	0
M	0	$-C_n$	0	$-P_n e_n$

These equations are now solved as follows (cf. Chapter III, Plate 16):

From equation δ_0 $S_0 = \alpha_0 M_0 + \beta_0$.
Substituting this value of S_0 in equation C_1 $C_1 = \alpha_0' M_0 + \beta_0'$.
Substituting this value of S_0 in equation M_0 $M_0 = \alpha_1 M_1 + \beta_1$.
Substituting this value of M_0 in above value of S_0 $S_0 = \alpha_1' M_1 + \beta_1'$.
Substituting this value of M_0 in above value of C_1 $C_1 = \alpha_1'' M_1 + \beta_1''$.
Substituting this value of C_1 in equation δ_1 $S_1 = \alpha_1''' M_1 + \beta_1'''$.
Substituting this value of S_1 and C_1 in equation C_2 $C_2 = \alpha_1^{iv} M_1 + \beta_1^{iv}$.
Substituting this value of S_1 in equation M_1 $M_1 = \alpha_2 M_2 + \beta_2$.
Substituting this value of M_1 in above value of S_1 $S_1 = \alpha_2' M_2 + \beta_2'$.
Substituting this value of M_1 in above value of C_2 $C_2 = \alpha_2'' M_2 + \beta_2''$.
Substituting this value of C_2 in equation δ_2 $S_2 = \alpha_2''' M_2 + \beta_2'''$.
Substituting this value of S_2 and C_2 in equation C_3 $C_3 = \alpha_2^{iv} M_2 + \beta_2^{iv}$.

The solution may thus be continued as above for all succeeding stories. In this solution the Greek letter coefficients have the following values.

VALUES OF GREEK LETTER COEFFICIENTS.

Zero Story.

S_0	$\alpha_0 = -a_0^\delta \div i_0^\delta$	$\beta_0 = 0$
C_1	$\alpha_0' = a_0^c + i_0^c \alpha_0$	$\beta_0' = 0$

First Story.

M_0	$\alpha_1 = 1 \div (1 + i_0^M \alpha_0)$	$\beta_1 = z_0^M \div (1 + i_0^M \alpha_0)$
S_0	$\alpha_1' = \alpha_0 \alpha_1$	$\beta_1' = \alpha_0 \beta_1$
C_1	$\alpha_1'' = \alpha_0' \alpha_1$	$\beta_1'' = \alpha_0' \beta_1$
S_1	$\alpha_1''' = (-a_1^\delta - s_1^\delta \alpha_1'') \div i_1^\delta$	$\beta_1''' = -s_1^\delta \beta_1'' \div i_1^\delta$
C_2	$\alpha_1^{iv} = a_1^c + i_1^c \alpha_1''' + \alpha_1''$	$\beta_1^{iv} = i_1^c \beta_1''' + \beta_1''$

Second Story

M_1	$\alpha_2 = 1 \div (1 + i_1^M \alpha_1''')$	$\beta_2 = (z_1^M - i_1^M \beta_1''') \div (1 + i_1^M \alpha_1''')$
S_1	$\alpha_2' = \alpha_1''' \alpha_2$	$\beta_2' = \beta_1''' + \alpha_1''' \beta_2$
C_2	$\alpha_2'' = \alpha_1^{iv} \alpha_2$	$\beta_2'' = \beta_1^{iv} + \alpha_1^{iv} \beta_2$
S_2	$\alpha_2''' = (-a_2^\delta - s_2^\delta \alpha_2'') \div i_2^\delta$	$\beta_2''' = -s_2^\delta \beta_2'' \div i_2^\delta$
C_3	$\alpha_2^{iv} = a_2^c + i_2^c \alpha_2''' + \alpha_2''$	$\beta_2^{iv} = i_2^c \beta_2''' + \beta_2''$

The values of these coefficients for all other stories will be the same as for the second story if proper values are assigned to the subscripts in place of those given.

Application of Theory.—The following example will be taken to illustrate the application of this method of solution, as well as to furnish data for discussion.

Assume the column five stories in height, all story heights, c, equal to 100 in., and the moment of inertia of the column section constant for all sections and equal to $1{,}000''^4$. Also assume, the eccentric loads P to be 10,000 ℔ each and their eccentricities, e, all the same and equal to 10 in. The following table gives the values of the symbolic coefficients a, i, s, and z.

Coefficient.	Story.				
	0	1	2	3	4
a^c	0.1	0.1	0.1	0.1	0.1
a^δ	5.0	5.0	5.0	5.0	5.0
a^M	0	0	0	0	0
i^c	−5.0	−5.0	−5.0	−5.0	−5.0
i^δ	−166.67	−166.67	−166.67	−166.67	−166.67
i^M	−100.00	−100.00	−100.00	−100.00	−100.00
s^c	1.0	1.0	1.0	1.0	1.0
s^δ	100.00	100.00	100.00	100.00	100.00
s^M	0	0	0	0	0
z^c	0	0	0	0	0
z^δ	0	0	0	0	0
z^M	−100,000	−100,000	−100,000	−100,000	−100,000

Of course, for those stories where loads are left off z will be 0.

The solution is now made for the following cases:

Case I.—Load P_4 only.

Case II.—Loads P_4 and P_3 only.

Case III.—Loads P_4, P_3, and P_2 only.

Case IV.—Loads P_4, P_3, P_2, and P_1 only.

Case V.—Loads P_4, P_3, P_2, P_1, and P_0.

The solutions for all five cases are given in the following table which, in form, corresponds to the table of Greek letter coefficients. The first and second column under each case gives values of α and β, while the third column gives values of the quantities S, M, and C, as shown in the corresponding lines at the left of the table. The third column, in each case, is calculated from the bottom up because S_4 will be the first quantity found and will be determined by

	α, All Cases.	Case I. β, Case I.	Case I. Results.	Case II. β, Case II.	Case II. Results.	Case III. β, Case III.	Case III. Results.	Case IV. β, Case IV.	Case IV. Results.	Case V. β, Case V.	Case V. Results.
S_0	α_0 +0.03	β_0 0	+ 8.3	β_0 0	− 8.3	β_0 0	+ 49.6	β_0 0	− 165.9	β_0 0	+ 637.5
C_1	α_0' −0.05	β_0' 0	− 13.9	β_0' 0	+ 13.8	β_0' 0	− 82.8	β_0' 0	+ 276.5	β_0' 0	−1,062.5
M_0	α_1 −0.50	β_1 0	+ 277.5	β_1 0	− 275.0	β_1 0	+1,655	β_1 0	−5,530	β_1 +50,000	+21,250
S_0	α_1' −0.015	β_1' 0	+ 8.3	β_1' 0	− 8.3	β_1' 0	+ 49.7	β_1' 0	− 165.7	β_1' + 1,500	+ 639
C_1	α_1'' +0.025	β_1'' 0	− 13.9	β_1'' 0	+ 13.8	β_1'' 0	− 82.7	β_1'' 0	+ 276	β_1'' − 2,500	− 1,063
S_1	α_1''' +0.045	β_1''' 0	− 25.0	β_1''' 0	+ 24.8	β_1''' 0	− 149.0	β_1''' 0	+ 497.5	β_1''' − 1,500	+ 1,085
C_2	α_1^{iv} −0.100	β_1^{iv} 0	+ 55.5	β_1^{iv} 0	− 55.0	β_1^{iv} 0	+ 331.0	β_1^{iv} 0	−1,105.0	β_1^{iv} + 5,000	− 745
M_1	α_2 −0.285	β_2 0	− 55.5	β_2 0	+ 550	β_2 0	−3,310	β_2 +28,550	+11,050	β_2 +71,400	+57,450
S_1	α_2' −0.0128	β_2' 0	− 25.0	β_2' 0	+ 24.8	β_2' 0	− 149.0	β_2' + 1,285	+ 498	β_2' + 1,715	+ 1,086
C_2	α_2'' +0.0285	β_2'' 0	+ 55.5	β_2'' 0	− 55.0	β_2'' 0	+ 331.0	β_2'' − 2,855	− 1,105	β_2'' − 2,140	− 745
S_2	α_2''' +0.0471	β_2''' 0	+ 91.8	β_2''' 0	− 90.9	β_2''' 0	+ 548.0	β_2''' − 1,713	+ 1,177	β_2''' − 1,284	+ 1,026
C_3	α_2^{iv} −0.1070	β_2^{iv} 0	− 208	β_2^{iv} 0	+ 207	β_2^{iv} 0	−1,242	β_2^{iv} + 5,710	− 850	β_2^{iv} + 4,280	− 960
M_2	α_3 −0.270	β_3 0	+1,945	β_3 0	−1,930	β_3 +27,000	+11,600	β_3 +73,100	+61,280	β_3 +61,600	+48,870
S_2	α_3' −0.0127	β_3' 0	+ 91.4	β_3' 0	− 90.9	β_3' + 1,272	+ 548	β_3' + 1,702	+ 1,145	β_3' + 1,616	+ 1,017
C_3	α_3'' +0.0289	β_3'' 0	− 208	β_3'' 0	+ 207	β_3'' − 2,885	− 1,235	β_3'' − 2,120	− 855	β_3'' − 2,320	− 960
S_3	α_3''' +0.0473	β_3''' 0	− 340	β_3''' 0	+ 338	β_3''' − 1,731	+ 969	β_3''' − 1,272	+ 798	β_3''' − 1,392	+ 838
C_4	α_3^{iv} −0.1076	β_3^{iv} 0	+ 773	β_3^{iv} 0	− 769	β_3^{iv} + 5,770	− 360	β_3^{iv} + 4,240	− 470	β_3^{iv} + 4,640	− 430
M_3	α_4 −0.268	β_4 0	−7,200	β_4 +26,800	+7,150	β_4 +73,200	+57,000	β_4 +61,000	+43,820	β_4 +64,000	+47,100
S_3	α_4' −0.0127	β_4' 0	− 340	β_4' + 1,266	+ 338	β_4' + 1,724	+ 956	β_4' + 1,618	+ 807	β_4' + 1,638	+ 840
C_4	α_4'' +0.0288	β_4'' 0	+ 774	β_4'' − 2,880	− 765	β_4'' − 2,100	− 358	β_4'' − 2,320	− 478	β_4'' − 2,250	− 435
S_4	α_4''' +0.0473	β_4''' 0	+1,267	β_4''' − 1,728	+1,737	β_4''' − 1,260	+ 1,600	β_4''' − 1,392	+ 1,638	β_4''' − 1,350	+ 1,630
C_5	α_4^{iv} −0.1076	β_4^{iv} 0	−2,885	β_4^{iv} + 5,760	−2,140	β_4^{iv} + 4,200	− 2,300	β_4^{iv} + 4,640	− 2,250	β_4^{iv} + 4,500	− 2,280
M_4	α_5 0	β_5 +26,800	+26,800	β_5 +73,300	+ 73,300	β_5 +60,500	+60,500	β_5 +64,000	+64,000	β_5 +63,000	+63,000
		M_5'	−99,900	M_5'	−100,400	M_5'	−99,500	M_5'	−99,800	M_5'	−100,000

$S_4 = \beta'_5$, since, in the equation $S_4 = \alpha'_5 M_5 + \beta'_5$, $M_5 = 0$ as there is no restraining flexural influence at the top of the column. The column α will be the same for all five cases since α is independent of the type of loading; this column is therefore only given once. As will be noted frequent checks are obtained in the last column in each case. The calculations are as follows.

M'_5 represents the bending moment just *below* the load P_4.

Now, by combining the results above four other important cases are secured as follows:

Case VI.—Load P_0 only—by subtracting Case IV from Case V.

Case VII.—Load P_1 only—by subtracting Case III from Case IV.

Case VIII.—Load P_2 only—by subtracting Case II from Case III.

Case IX.—Load P_3 only—by subtracting Case I from Case II.

Figs. 7, *b*, show the bending moment diagrams and the deflection curves (values of Ey) for all nine cases, to scale.

Scale for bending moments 1 in. = 240,000 in. lbs.

Scale for Deflections (Ey) 1 in. = 80,000 in.

The values of M, S, H, and C for all cases are given in the following table. Figs. 7, *b*, clearly show the fact that the effect of the eccentric load is very small at points two or more stories away from the load.

PRESENT PRACTICE IN DESIGNING FOR ECCENTRIC LOADS.

Class A Buildings.—Referring to Fig. 5, *a*, of Chapter II, suppose the structure there shown to have diagonal bracing and it is desired to design the two story column section marked "*AA*." Evidently the lower or second story portion of the column will receive the heaviest load and the axial stress in this portion will consist of the dead, live, and wind loads from above plus the column weight and fireproofing for the second story.

The eccentric load P_n^A would be considered as producing, at the point marked "x" on the extreme outer fibre, a unit compressive stress equal to $P_n^A e_n^A v/I$ and the effect of all other eccentric loads, above or below, on the design of this column section is regarded as nil.

Class B Buildings.—As was shown in Chapter II, if the girders are considered rigid (and this is the assumption made in designing

	Case I.				Case II.				Case III.			
	M	S	H	C	M	S	H	C	M	S	H	C
0	+ 277.5	+ 8.3	− 33.3	− 13.9	− 275	− 8.3	+ 33.1	+ 13.8	+ 1,655	+ 49.7	− 198.7	− 82.7
1	− 555	− 25.0	+ 116.4	+ 55.5	+ 550	+ 24.8	− 115.7	− 55.0	− 3,310	− 149.0	+ 697.0	+ 331.0
2	+ 1,945	+ 91.6	− 431.4	− 208.0	− 1,930	− 90.9	+ 428.9	+ 207.0	+11,600	+ 548.0	+ 408.0	−1,238.0
3	− 7,200	− 340.0	+1,607.0	+ 774.0	+ 7,150	+ 338.0	+1,399.0	− 767.0	+57,000	+ 956.0	+ 644.0	− 359.0
4	+26,800	+1,267.0	−1,267.0	−2,885.0	+73,300	+1,737.0	−1,737.0	−2,140.0	+60,500	+1,600.0	−1,600.0	−2,300.0
	Case IV.				Case V.				Case VI.			
0	− 5,530	− 165.9	+ 663.7	+ 276.0	+21,250	+ 639.0	+ 447.0	−1,063.0	− 552.5	− 16.6	+ 66.4	+ 27.7
1	+11,050	+ 497.8	+ 647.0	−1,105.0	+57,450	+1,086.0	− 69.0	− 745.0	+ 1,105.0	+ 49.8	− 232.1	− 110.5
2	+61,280	+1,145.0	− 338.0	− 852.0	+48,870	+1,017.0	− 177.0	− 960.0	− 3,875.0	− 182.3	+ 860.3	+ 415.0
3	+43,820	+ 807.0	+ 831.0	− 474.0	+47,100	+ 840.0	+ 790.0	− 432.0	+14,350.0	+ 678.0	− 208.0	−1,541.0
4	+64,000	+1,638.0	−1,638.0	−2,250.0	+63,000	+1,630.0	−1,630.0	−2,280.0	+46,500.0	+ 470.0	− 470.0	+ 745.0
	Case VII.				Case VIII.				Case IX.			
0	+ 1,930	+ 58.0	− 231.8	− 96.5	− 1,185	− 215.4	+ 862.4	+ 358.7	+26,780	+ 804.7	− 216.7	−1,339.0
1	− 3,860	− 173.8	+ 812.7	+ 386.0	+14,360	+ 647.0	− 50.0	−1,436.0	+46,400	+ 588.0	− 716.0	+ 360.0
2	+13,530	+ 638.9	− 20.9	−1,445.0	+49,680	+ 597.0	− 746.0	+ 386.0	−12,410	− 128.0	+ 161.0	− 108.0
3	+49,850	+ 618.0	− 755.0	+ 408.0	−13,180	− 149.0	+ 187.0	− 115.0	+ 3,280	+ 33.0	− 41.0	+ 42.0
4	−12,800	− 137.0	+ 137.0	− 160.0	+ 3,500	+ 38.0	− 38.0	+ 50.0	− 1,000	− 8.0	+ 8.0	− 30.0

practice) the column can receive no bending moment from eccentric loading, no matter how large the load or its eccentricity, *i. e.*, the column is designed for axial stress and bending due to wind only.

CONCLUSIONS POINTED OUT BY PROFESSOR HELLER AND VERIFIED IN THIS CHAPTER.

First. The maximum moment for eccentric loads on a column will always occur for a load at the roof line and there equals Pe (considering all loads and eccentricities as equal).

Second. For equal loads with equal eccentricities at *all* floors, the bending moment approaches the constant value $\frac{1}{2}Pe$ for floors about three stories or more from either top or bottom of the building.

Third. For a single load at any point, the bending moment in the column passes from a value of about $\frac{1}{2}Pe$ just above the load, through zero, to a value of approximately $-\frac{1}{2}Pe$ just below the load.

Professor Heller's figures are based on a column hinged at the anchorage. His results agree very well with the results here given, based on a column fixed vertically at the anchorage.

CHAPTER V.

A STUDY OF THE EFFECT OF HORIZONTAL AND VERTICAL LOADS ON A SINGLE PLATE GIRDER PORTAL. BY THREE METHODS.

In this chapter two portals of extremely different proportions are investigated. One of these is a high portal with comparatively large columns and a very light shallow girder, the other is a low portal with light columns and a deep rigid girder. These two extremes were chosen in order to compare the theory based on rigid girders with that based on an entirely elastic structure. The stresses and distortions are first calculated for each portal on the assumption of rigid girders; then these quantities are calculated by the methods given in Chapter III. Finally each structure is treated as an *arch* of variable moment of inertia and the stresses calculated by Howe's summation method. (See "A Treatise on Arches," by M. A. Howe.) The two portals will be referred to as P_1 and P_2, P_1 being the tall one. The properties assumed for each portal are given as follows:

	P_1	P_2		P_1	P_2
c_0	200	100	$A_0{}^B$	20	15
d_0	20	50	$A_0{}^a$	20	25
b	200	200	F_0	10,000	10,000
$I_0{}^A$	1,000	500	W_0	300	300
$I_0{}^B$	1,000	500	ΣF	10,000	10,000
$I_0{}^a$	1,200	5,000	V^A	7.00	7.00
$A_0{}^A$	20	15	V^B	7.00	7.00

Stresses and Deformation — Rigid Girders.

Portal P_1.—For Floor Load w_0 Only.—The total floor load will be $w_0 b$ = 300 ℔ × 200 in. = 60,000 ℔. Referring to Chapter II, by symmetry

$$h^A = -h^B = 100 \text{ in.}, \quad X = 60{,}000 \times 0 = 0; \quad Y = 60{,}000.$$

$$s = 0, \quad p = \frac{60{,}000}{20 + 20} = 1{,}500 \text{ ℔ per sq. in.,}$$

$$V_0^A = V_0^B = 1{,}500 \times 20 = 30{,}000 \text{ ℔.}$$

$$S_0^A = S_0^B = 0$$

and hence $H_0 = 0$.

$$M_0^A = M_0^B = 0,$$

hence the column receives no bending.

Girder stresses,

top flange,

$$\text{Max. compression} = 30{,}000 \times \frac{100}{20} - \frac{300 \times \overline{100^2}}{40} = 75{,}000 \text{ lb} \quad (x = 100 \text{ in.}),$$

$$\text{Max. tension} = 0 \qquad (x = 0 \text{ in. and } x = 200 \text{ in.}).$$

bottom flange,

$$\text{Max. tension} = 75{,}000 \text{ lb} \qquad (x = 100 \text{ in.}),$$

$$\text{Max. compression} = 0 \qquad (x = 0 \text{ in. and } x = 200 \text{ in.}).$$

The girder does not deform (by assumption). The columns do not change in length (by assumption).

For Wind Load F_0 Only.—$h^A = - h^B = 100$ in. as above;

$$X = 10{,}000 \times 110 = 1{,}100{,}000 \text{ in. lb}; \quad Y = 0.$$

$$s = + \frac{1{,}100{,}000}{20 \times \overline{100^2} + 20 \times \overline{100^2}} = + 2.75 \text{ lb per sq. in.}$$

$$p = 0; \quad s^A = - 2.75 \times 100 = - 275 \text{ lb per sq. in.} = - s^B.$$

$$V_0^A = - V_0^B = - 275 \times 20 = - 5{,}500 \text{ lb};$$

$$S_0^A = S_0^B = \frac{1{,}000}{2{,}000} \times 10{,}000 = + 5{,}000 \text{ lb};$$

hence

$$H_0 = S_0^B = + 5{,}000 \text{ lb};$$

$$M_0^A = M_0^B = 5{,}000 \times \frac{200}{2} = + 500{,}000 \text{ in. lb}.$$

Max. column compressive fibre stress

$$= f^B = \frac{500{,}000 \times 7.00}{1{,}000} + 275 = 3{,}500 + 275 = 3{,}775 \text{ lb per sq. in.}$$

Girder stresses,

top flange,

$$\text{Max. compression} \frac{5{,}000 \times 200}{40} + 5{,}000 = 30{,}000 \text{ lb} \quad (x = 0),$$

$$\text{Max. tension}\ \frac{5,500 \times 200}{20} - 30,000 = 25,000 \text{ lb} \quad (x = 200 \text{ in.}).$$

bottom flange,

$$\text{Max. tension}\ \frac{5,000 \times 240}{40} - 5,000 = 25,000 \text{ lb} \qquad (x = 0),$$

$$\text{Max. compression}\ \frac{5,500 \times 200}{20} - 25,000 = 30,000 \text{ lb}$$
$$(x = 200 \text{ in.}).$$

The girder does not deform.

For the columns

$$\delta_0^A = \delta_0^B = + \frac{5,000 \times \overline{200}^3}{12,000} = + 3,333,333.$$

Portal P_2—For Floor Load w_0 Only.—All calculations for portal P_1 hold also for this portal excepting only those for girder stresses. These girder stresses will be 20/50 times those given for P_1, since this is the ratio of the two girder depths. The girder stresses are then

For top flange, max. compression $= 0.4 \times 75,000 = 30,000$ lb. Max tension $= 0$.

For bottom flange, max. tension $= 0.4 \times 75,000 = 30,000$ lb. Max. compression $= 0$.

For Wind Load F_0 Only.—

$$h^A = - h^B = 100 \text{ in.}; \quad X = 10,000 \times 75 = + 750,000 \text{ in. lb};$$
$$Y = 0.$$

$$s = + \frac{750,000}{15 \times \overline{100}^2 + 15 \times \overline{100}^2} = + 2.50; \quad p = 0.$$

$$s^A = - 2.50 \times 100 = - 250 \text{ lb per sq. in.} = - s^B.$$

$$V_0^A = - V_0^B = - 250 \times 15 = - 3,750 \text{ lb};$$

$$S_0^A = S_0^B = \frac{500}{1,000} \times 10,000 = + 5,000 \text{ lb};$$

hence

$$H_0 = S_0^B = + 5,000 \text{ lb}.$$

$$M_0^A = M_0^B = + 5,000 \times 50 = + 250,000 \text{ in. lb}.$$

Max. column compressive fibre stress

$$= f^B = \frac{250{,}000 \times 7.00}{500} + 250 = 3{,}500 + 250 = 3{,}750 \text{ lb per sq. in.}$$

Girder stresses,

top flange,

Max. compression, $\frac{5{,}000 \times 100}{100} + 5{,}000 = + 10{,}000$ lb $(x = 0)$,

Max. tension, $\frac{3{,}750 \times 200}{50} - 10{,}000 = + 5{,}000$ lb $(x = 200)$.

bottom flange,

Max. tension, $\frac{5{,}000 \times 200}{100} - 5{,}000 = + 5{,}000$ lb $(x = 0)$,

Max. compression, $\frac{3{,}750 \times 200}{50} - 5{,}000 = + 10{,}000$ lb $(x = 200)$.

The girder does not deform. For the column,

$$\delta_0^A = \delta_0^B = + \frac{5{,}000 \times \overline{100}^3}{6{,}000} = + 833{,}333.$$

Stresses and Deformations—Entire Structure Elastic.

Portal P_1 (both loadings calculated separately but in the same table).—Referring to Plate 15, the values of the symbolic coefficients become as shown on page 91.

The simplified equations are:

$$H_0 = a_0^A M_0^A + b_0^A M_0^B + i_0^A S_0^B + z_0^A,$$

$$0 = a_0^B M_0^A + b_0^B M_0^B + i_0^B S_0^B + l_0^B H_0 + z_0^B,$$

$$0 = a_0^C M_0^A + b_0^C M_0^B + i_0^C S_0^B + l_0^C H_0 + z_0^C.$$

Note that, although $S_1^A = 0$, the coefficient "l_0" was carried in the solution. Now, referring to Plate 17, the solution for the unknowns C_1^A, C_1^B, Δ_0^a, S_0^A and S_0^B is made by filling out calculations corresponding to the values given in the blanks of this plate, using the coefficients given in the above table in so doing. For coefficients of C_1^A, C_1^B, and Δ_0^a use those given in the upper part of the above table excepting where other values of the coefficients are

SYMBOLIC COEFFICIENTS — PORTAL P_1.

	a_0	b_0	e_0	f_0	i_0	l_0	s_0	t_0	w_0	P_0	z_0 For F_0.	z_0 For w_0.
$C-A$	+ 0.2	0.0	0	0	− 20.0	0	0	0	0	0	0.0	0
$C-B$	0.0	+ 0.2	0	0	+ 20.0	0	0	0	0	0	− 200,000.0	0
$\delta-A$	+20.0	0.0	0	0	−1,333.3	0	0	0	0	0	0.0	0
$\delta-B$	0.0	+20.0	0	0	+1,333.3	0	0	0	0	0	−13,333,333.3	0
$H-a$	0.0	0.0	0	0	− 1.0	+ 1.0	0	0	0	0	+ 10,000	0
$\lambda-a$	0.0	0.0	0	0	− 10.0	+ 10.0	0	0	0	0	+ 100,000	0
$V-A$	+ 0.005	+ 0.005	0	0	0	0	0	0	0	0	− 10,500	+ 30,000
$V-B$	− 0.005	− 0.005	0	0	0	0	0	0	0	0	+ 10,500	+ 30,000
$\alpha-A$	+ 0.0525	+ 0.0525	0	0	0	0	0	0	0	0	− 110,250	+ 315,000
$\alpha-B$	− 0.0525	− 0.0525	0	0	0	0	0	0	0	0	+ 110,250	+ 315,000
$\Delta-a$	− 0.1050	− 0.1050	0	0	0	0	0	0	0	0	+ 220,500	0
$Q-a$	− 0.000,833	0.0	0	0	+ 0.175	+ 0.00833	0	0	0	0	0	0
$R-a$	+ 0.000,004,167	+ 0.000,004,167	0	0	0	0	0	0	0	0	− 8.75	+ 25.0
$A-a$	+22.0	−22.0	0	0	−3,056.7	− 10.0	0	0	0	0	+15,233,333.3	0
$B-a$	− 0.2833	+ 0.2833	0	0	+ 75.0	+ 1.6667	0	0	0	0	− 375,000	+ 166,667
$C-a$	− 5.4505	+51.21	0	0	+7,500.0	+166.667	0	0	0	0	−63,553,833.3	+16,666,667
Values of coefficients affected by transformed equations—see Plate 15.												
$C-A$					+ 20.0					0	− 200,000	0
$C-B$					− 20.0					0	0	0
$\Delta-a$					0.0					0	+ 220,500	0
$A-a$					+3,066.7					0	−15,333,333	0
$B-a$					− 76.667					0	+ 375,000	+ 166,667
$C-a$					−7,666.7					0	+11,446,167	+16,666,667
Final coefficients after simplifying equations A, B, and C—see text, Chap. III.												
$A-a$	+ 2.2000	− 2.2000			+ 306.67						− 1,533,333	0
$B-a$	+ 5.8189	+ 2.4189			+ 460.00	− 10.0					− 6,939,690	− 1,000,000
$C-a$	+ 2.4189	+ 5.8189			− 460.00	+ 10.0					− 2,439,690	+ 1,000,000

SOLUTION OF EQUATIONS.

			For F_0	For W_0
A_0 +0.960 +1,784 +1.312 −1,012 den. = +772 +2.272	B_0 0	C_0 +3.975 −0.596 +3.379	D_0 +2,758,000 − 914,000 +1,844,000	D_0 +397,500 0 +397,500
A_0' +1.018 $A_0 - A_0' = +1.832$ −0.578 + 741.5 +1012.0 den. = +1,753 +0.440	B_0' 0	C_0' −1.752 +0.262 −1.490	D_0' +427,500 +402,500 +830,000	D_0' −175,200 0 −175,200
α_0 −1.847 −0.811 −2.658	B_0 0	γ_0 0	δ_0 +1,029,000 − 443,000 +586,000	δ_0 −217,300 − 95,500 −312,800
α_0' $\alpha_0 + \alpha_0' = -0.003$ +2.655	B_0' 0	γ_0' 0	δ_0' $\delta_0 + \delta_0' = +1,139,500$ +553,500	δ_0' $\delta_0 + \delta_0' = -300$ +312,500
α_0'' +0.00326 +0.01905 +0.01904 +0.04135	B_0'' 0	γ_0'' 0	δ_0'' +4,990 −4,200 +3,967 +4,757	δ_0'' 0 +2,245 +2,240 +4,485
α_0''' −0.5316 +0.8270 +0.2954	β_0''' 0	γ_0''' 0	δ_0''' −200,000 +117,200 + 95,140 +12,340	δ_0''' 0 −62,560 +89,700 +27,140
α_0^{iv} +0.531 −0.827 −0.296	β_0^{iv} 0	γ^{iv} 0	δ_0^{iv} 0 +110,700 − 95,140 +15,560	δ_0^{iv} 0 +62,500 −89,700 −27,200
α_0^{v} +0.000315	β_0^{v} 0	γ_0^{v} 0	δ_0^{v} +220,500 −119,600 +100,900	δ_0^{v} 0 +31.5 +31.5

shown in the middle part of the table under "Coefficients for Transformed Equations," when these should be used. For the coefficients in Equations A, B, and C, use the "Final Coefficients" as above given. The tabular calculations corresponding to Plate 17 are as shown in the table on page 92.

Now, referring to the "Solution" on Plate 16 and using the coefficients in the above and preceding table, the values of the unknowns are deduced for each loading as follows:

For Wind Load F_0 Only.

$$S_0^B = +0.04135 H_0 + 4,757.$$

But

$$H_0 = S_0^B,$$

hence

$$0.9586 S_0^B = +4,757 \quad \text{or} \quad S_0^B = +4,965 \text{ lb} = H_0,$$

$$\begin{aligned}
M_0^A &= -2.658\ H_0 + 586,000 = +572,800 \text{ in. lb},\\
M_0^B &= +2.655\ H_0 + 553,500 = +566,700 \text{ in. lb},\\
C_1^A &= +0.2954\ H_0 + 12,340 = +13,807,\\
C_1^B &= -0.296\ H_0 + 15,560 = +14,090,\\
\Delta_0^a &= +0.0003\ H_0 + 100,900 = +100,900,\\
S_0^A &= \Sigma F - S_0^B = 10,000 - 4,965 = +5,035,\\
X_0^A &= +\frac{572,800}{5,035} = +113.8 \text{ in.},\\
X_0^B &= +\frac{566,700}{4,965} = +114.1 \text{ in.},\\
\delta_0^A &= +20.0\ M_0^A - 1,333.3\ S_0^A = \qquad +4,742,700 \text{ in.},\\
\delta_0^B &= +20.0\ M_0^B + 1,333.3\ S_0^A - 13,333,333 = +4,714,000 \text{ in.},\\
\lambda_0^a &= -10.0\ S_0^A + 100,000 = \qquad +\ 49,650 \text{ in.},\\
V_0^A &= +0.005\ M_0^A + 0.005\ M_0^B - 10,500 = -4,802 \text{ lb} = -V_0^B,\\
\alpha_0^A &= +0.0525\ M_0^A + 0.0525\ M_0^B - 110,250 \text{ ft.}\\
&= -50,427 \text{ in.} = -\alpha_0^B.
\end{aligned}$$

Girder Stresses.

Top flange:

$$\text{Max. comp.} = \tfrac{200}{20} S_0^A - \tfrac{1}{20} M_0^A + \tfrac{1}{2} F_0 = +26,710 \text{ lb} \quad (x = 0 \text{ in.}),$$

$$\text{Max. tens.} = \tfrac{200}{20} S_0^B - \tfrac{1}{20} M_0^B = +21,315 \text{ lb} \quad (x = 200 \text{ in.}).$$

Bottom flange:

$$\text{Max. tens.} \quad = \tfrac{220}{20} S_0^A - \tfrac{1}{20} M_0^A - \tfrac{1}{2} F_0 = +\ 21{,}745 \text{ lb} \quad (x = 0),$$
$$\text{Max. comp.} = \tfrac{220}{20} S_0^B - \tfrac{1}{20} M_0^B = +\ 26{,}280 \text{ lb} \quad (x = 200 \text{ in.}).$$

Max. Compressive Column Fibre Stress.

$$\text{For Col. } A = \frac{572{,}800 \times 7.00}{1{,}000} - \frac{4{,}802}{20} = 4{,}010 - 240$$
$$= +\ 3{,}770 \text{ lb per sq. in.}$$

This occurs at the inside bottom fibre.

$$\text{For Col. } B = \frac{566{,}700 \times 7.00}{1{,}000} + \frac{4{,}802}{20} = 3{,}967 + 240$$
$$= +\ 4{,}207 \text{ lb per sq. in.}$$

This occurs at the outside bottom fibre.

Check.

Using the geometrical check of Equation A,

$$\left.\begin{aligned} \delta_0^A + \frac{d_0}{2} C_1^A - \lambda_0^a &= +\ 4{,}831{,}120 \\ \delta_0^B + \frac{d_0}{2} C_1^B &= +\ 4{,}854{,}900 \end{aligned}\right\} \text{checks.}$$

For Floor Load w_0 Only.

$$S_0^B = +\ 0.04135\ H_0 + 4{,}485.$$

But

$$H_0 = S_0^B,$$

hence

$$0.9586\ S_0^B = +\ 4{,}485 \quad \text{or} \quad S_0^B = +\ 4{,}680 \text{ lb} = H_0,$$

$$\left.\begin{aligned} M_0^A &= -\ 2.658\ H_0 - 312{,}800 = -\ 325{,}200 \\ M_0^B &= +\ 2.655\ H_0 + 312{,}500 = +\ 324{,}900 \end{aligned}\right\} \begin{aligned} &\text{Average} \\ &= 325{,}050 \text{ in. lb,} \end{aligned}$$

$$\left.\begin{aligned} C_1^A &= +\ 0.2954\ H_0 + 27{,}140 = +\ 28{,}524 \\ C_1^B &= -\ 0.296\ \ H_0 - 27{,}200 = -\ 28{,}584 \end{aligned}\right\} \text{Average} = 28{,}554,$$

$$\Delta_0^a = +\ 0.0003\ H_0 + 31.5 = +\ 33. \quad \text{Should be } 0,$$

$$S_0^A = -\ S_0^B = -\ 4{,}680 \text{ lb},$$

$$X_0^A = X_0^B = \frac{325{,}050}{4{,}680} = +\ 69.4 \text{ in.}$$

$$\delta_0^A = +\,20.0\ M_0^A - 1{,}333.3\ S_0^A = -\,261{,}000 \text{ in.},$$
$$\delta_0^B = +\,20.0\ M_0^B + 1{,}333.3\ S_0^A = +\,261{,}000 \text{ in.},$$
$$\lambda_0^a = -\,10.0\ S_0^A = +\,46{,}800 \text{ in.},$$
$$V_0^A = +\,0.005\ M_0^A + 0.005\ M_0^B + 30{,}000 = +\,30{,}000 \text{ lb} = +\,V_0^B,$$
$$\alpha_0^A = +\,0.0525\ M_0^A + 0.0525\ M_0^B + 315{,}000 = +\,315{,}000 \text{ in.} = +\,\alpha_0^B.$$

Girder Stresses.

Top flange:

$$\text{Max. comp.} = \frac{200}{20} S_0^A - \frac{1}{20} M_0^A + \frac{100}{20} V_0^A - \frac{w_0\overline{100}^2}{2 \times 20}$$
$$= +\,44{,}450 \text{ lb} \quad (x = 100 \text{ in.}),$$

$$\text{Max. tens.} = -\tfrac{200}{20} S_0^A + \tfrac{1}{20} M_0^A = +\,30{,}550 \text{ lb}$$
$$(x = 0 \text{ in.}, \epsilon x = 200 \text{ in.}).$$

Bottom flange:

$$\text{Max. tens.} = \frac{220}{20} S_0^A - \frac{1}{20} M_0^A + \frac{100}{20} V_0^A - \frac{w_0\overline{100}^2}{2 \times 20}$$
$$= +\,39{,}770 \text{ lb} \quad (x = 100 \text{ in.}),$$

$$\text{Max. comp.} = -\tfrac{220}{20} S_0^A + \tfrac{1}{20} M_0^A = +\,35{,}230 \text{ lb}$$
$$(x = 0 \text{ in.}, \epsilon x = 200 \text{ in.}).$$

Max. Compressive Column Fibre Stress.

$$\text{For Col. } A = \frac{(200\ S_0^A - M_0^A)7.00}{1{,}000} + \frac{30{,}000}{20}$$
$$= +\,4{,}277 + 1{,}500 = +\,5{,}777 \text{ lb per sq. in.}$$

This occurs at the inside top fibre.

For Col. B,

Same as for Column A.

Check.

Using the geometrical check of Equation A,

$$\left.\begin{aligned} \delta_0^A + \frac{d_0}{2} C_1^A - \lambda_0^a &= -\,22{,}260 \\ \delta_0^B + \frac{d_0}{2} C_1^B &= -\,24{,}540 \end{aligned}\right\}$$ Considering the large quantities involved and the slide rule work (18 in. Mannheim) this checks.

Portal P_2 (both loadings calculated separately but in the same table).—Referring to Plate 15, the values of the symbolic coefficients become:

SYMBOLIC COEFFICIENTS—PORTAL P_2.

	a_0	b_0	e_0	f_0	i_0	l_0	s_0	t_0	w_0	P_0	z_0	
											For F_0.	For w_0.
$C-A$	+ 0.2	0.0	0	0	− 10.0	0.0	0	0	0	0	0.0	0.0
$C-B$	0.0	+ 0.2	0	0	+ 10.0	0.0	0	0	0	0	− 100,000.0	0.0
$\delta-A$	+10.0	0.0	0	0	− 333.33	0.0	0	0	0	0	0.0	0.0
$\delta-B$	0.0	+10.0	0	0	+ 333.33	0.0	0	0	0	0	− 3,333,333.0	0.0
$H-a$	0.0	0.0	0	0	− 1.00	+ 1.0	0	0	0	0	+ 10,000.0	0.0
$\lambda-a$	0.0	0.0	0	0	− 8.00	+ 8.0	0	0	0	0	+ 80,000.0	0.0
$V-A$	+ 0.005	+ 0.005	0	0	0.0	0.0	0	0	0	0	− 6,250.0	+ 30,000.0
$V-B$	− 0.005	− 0.005	0	0	0.0	0.0	0	0	0	0	+ 6,250.0	+ 30,000.0
$\alpha-A$	+ 0.04167	+ 0.04167	0	0	0.0	0.0	0	0	0	0	− 52,083.0	+ 250,000.0
$\alpha-B$	− 0.04167	− 0.04167	0	0	0.0	0.0	0	0	0	0	+ 52,083.0	+ 250,000.0
$\Delta-a$	− 0.0833	− 0.0833	0	0	0.0	0.0	0	0	0	0	+ 104,167.0	0.0
$Q-a$	− 0.000200	0.0	0	0	+ 0.025	+ 0.005	0	0	0	0	0.0	0.0
$R-a$	+ 0.0000010	+ 0.0000010	0	0	0.0	0.0	0	0	0	0	− 1.25	+ 6.0
$A-a$	+15.000	−15.000	0	0	−1,158.67	− 8.0	0	0	0	0	+ 5,753,333	0.0
$B-a$	− 0.22	+ 0.22	0	0	+ 25.0	+ 1.0	0	0	0	0	− 125,000	+ 40,000.0
$C-a$	− 1.25	+42.75	0	0	+2,500.0	+100.0	0	0	0	0	−23,437,500	+4,000,000.0
Values of coefficients affected by transformed equations, see Plate 15.												
$C-A$					+ 10.0					0	− 100,000	0.0
$C-B$					− 10.0					0	0	0.0
$\Delta-a$					0.0					0	+ 104,167	0.0
$A-a$					+1,166.67					0	− 5,753,333	0.0
$B-a$					− 26.0					0	+ 125,000	+ 40,000.0
$C-a$					−2,600					0	+ 1,562,500	+ 400,000.0
Final coefficients—after simplifying equations A, B, and C, see text, Chap. III.												
$A-a$	+ 1.875	− 1.875			+ 145.83						− 729,167	0
$B-a$	+21.0625	+10.0625			+ 650.00	− 25.0					−11,328,000	−1,000,000
$C-a$	+10.0625	+21.0625			− 650.00	+ 25.0					− 5,078,125	+1,000,000

SOLUTION OF EQUATIONS.

A_0 +0.7915 +3,074 +0.6565 − −1,218 den = +1,856 +1.4480	B_0 0	C_0 +1.965 −0.350 +1.615	D_0 +890,000 −255,300 +634,700	D_0 +78,600 0 +78,600
A_0' A_0-A_0' = +0.757 +1.144 +1,468 −0.453 +1,218 den = +2,686 +0.691	B_0' 0	C_0' −1.357 +0.242 −1.115	D_0' +276,000 +176,300 +452,300	D_0' −54,280 0 −54,280
α_0 −2.133 −1.473 −3.606	β_0 0	γ_0 0	δ_0 +865,500 −579,000 +286,500	δ_0 −104,000 − 71,700 −175,700
α_0' +2.132 +1.472 +3.604	β_0' 0	γ_0' 0	δ_0' +839,000 −597,500 +241,500	δ_0' +103,900 + 71,750 +175,650
α_0'' +0.00686 +0.0464 +0.0464 +0.0997	β_0'' 0	γ_0'' 0	δ_0'' +5,000 −3,685 +3,105 +4,420	δ_0'' 0 +2,259 +2,259 +4,518
α_0''' −0.7212 +0.997 +0.276	β_0''' 0	γ_0''' 0	δ_0''' −100,000 + 57,300 + 44,200 +1,500	δ_0''' 0 −35,140 +45,180 +10,040
α_0^{iv} +0.721 −0.997 −0.276	β_0^{iv} 0	γ_0^{iv} 0	δ_0^{iv} 0 +48,300 −44,200 +4,100	δ_0^{iv} 0 +35,140 −45,180 −10,040
α_0^{v} +0.3005 −0.3005 0	β_0^{v} 	γ_0^{v} 0	δ_0^{v} +104,167 − 23,875 − 20,125 +60,167	δ_0^{v} 0 −14,642 +14,642 0

Now, proceeding as described for the Portal P_1, the tabular calculations corresponding to Plate 17 are as given in the table on page 97.

Now, referring to the "solution" on Plate 16 and using the coefficients in the above and preceding tables, the values of the unknowns are deduced for each loading as follows:

For Wind Load F_0 Only.

$$S_0^B = + 0.0997 \, H_0 + 4{,}420.$$

But

$$H_0 = S_0^B;$$

hence

$$0.9003 \, S_0^B = + 4{,}420 \quad \text{or} \quad S_0^B = + 4{,}915 \text{ lb} = H_0,$$

$$M_0^A = - 3.606 \, H_0 + 286{,}500 = + 268{,}780 \text{ in. lb},$$

$$M_0^B = + 3.604 \, H_0 + 241{,}500 = + 259{,}220 \text{ in. lb},$$

$$C_1^A = + 0.276 \, H_0 + 1{,}500 = + 2{,}860,$$

$$C_1^B = - 0.276 \, H_0 + 4{,}100 = + 2{,}740,$$

$$\Delta_0^a = 0 \, H_0 + 60{,}167 = + 60{,}167,$$

$$S_0^A = \Sigma F - S_0^B = 10{,}000 - 4{,}915 = + 5{,}085 \text{ lb},$$

$$X_0^A = \frac{268{,}780}{5{,}085} = + 52.85 \text{ in.},$$

$$X_0^B = \frac{259{,}220}{4{,}915} = + 52.75 \text{ in.},$$

$$\delta_0^A = + 10.0 \, M_0^A - 333.33 \, S_0^A = + 992{,}800 \text{ in.},$$

$$\delta_0^B = + 10.0 \, M_0^B + 333.33 \, S_0^A - 3{,}333{,}333 = + 953{,}900 \text{ in.},$$

$$\lambda_0^A = - 8.0 \, S_0^A + 80{,}000 = + 39{,}320 \text{ in.},$$

$$V_0^A = + 0.005 \, M_0^A + 0.005 \, M_0^B - 6{,}250 = - 3{,}610 \text{ lb} = - V_0^B,$$

$$\alpha_0^A = + 0.0417 \, M_0^A + 0.0417 \, M_0^B - 52{,}083$$
$$= - 30{,}065 \text{ in.} = - \alpha_0^B,$$

Girder Stresses.

Top flange:

Max. comp. $= \frac{100}{50} S_0^A - \frac{1}{50} M_0^A + \frac{1}{2} F_0 = + 9{,}794$ lb ($x = 0$ in.)

Max. tens. $= \frac{100}{50} S_0^B - \frac{1}{50} M_0^B = + 4{,}646$ lb ($x = 200$ in.).

Bottom flange:

Max. tens. $= \frac{150}{50} S_0^A - \frac{1}{50} M_0^A - \frac{1}{2} F_0 = + 4{,}879$ lb ($x = 0$ in.),

Max. comp. $= \frac{150}{50} S_0^B - \frac{1}{50} M_0^B = + 9{,}561$ lb ($x = 200$ in.).

Max. Compressive Column Fibre Stress.

$$\text{For Col. } A = \frac{268{,}780 \times 7.00}{500} - \frac{3{,}610}{15} = 3{,}763 - 241$$
$$= +\,3{,}522 \text{ lb per sq. in.}$$

This occurs at the inside bottom fibre.

$$\text{For Col. } B = \frac{259{,}220 \times 7.00}{500} + \frac{3{,}610}{15} = 3{,}629 + 241$$
$$= +\,3{,}870 \text{ lb per sq. in.}$$

This occurs on the outside bottom fibre.

Checks.

Using the geometrical check of Equation A,

$$\left.\begin{aligned} \delta_0^A + \frac{d_0}{2} C_1^A - \lambda_0^a &= +\,1{,}025{,}000 \text{ in.} \\ \delta_0^B + \frac{d_0}{2} C_1^B \qquad &= +\,1{,}022{,}400 \text{ in.} \end{aligned}\right\} \text{checks.}$$

For Floor Load w_0 Only.

$$S_0^B = +\,0.0997\, H_0 + 4{,}518.$$

But

$$H_0 = S_0^B;$$

hence

$$0.9003\, S_0^B = +\,4{,}518 \quad \text{or} \quad S_0^B = +\,5{,}020 \text{ lb} = H_0,$$

$$M_0^A = -\,3.606\, H_0 - 175{,}700 = -\,193{,}800 \text{ in. lb},$$
$$M_0^B = +\,3.604\, H_0 + 175{,}650 = +\,193{,}800 \text{ in. lb},$$
$$C_1^A = +\,0.276\, H_0 + 10{,}040 = +\,11{,}425,$$
$$C_1^B = -\,0.276\, H_0 - 10{,}040 = -\,11{,}425,$$
$$\Delta_0^a = 0\, H_0 + 0 = 0,$$
$$S_0^A = -\,S_0^B = -\,5{,}020 \text{ lb},$$
$$X_0^A = X_0^B = \frac{193{,}800}{5{,}020} = +\,38.62 \text{ in.},$$

$$\delta_0^A = +\,10.0\, M_0^A - 333.33\, S_0^A = -\,264{,}700 \text{ in.},$$
$$\delta_0^B = +\,10.0\, M_0^B + 333.33\, S_0^A = +\,264{,}700 \text{ in.},$$
$$\lambda_0^A = -\,8.0\, S_0^A = +\,40{,}160 \text{ in.},$$

$$V_0^A = +0.005\, M_0^A + 0.005\, M_0^B + 30{,}000$$
$$= +30{,}000 \text{ lb.} = +V_0^B,$$
$$\alpha_0^A = +0.0417\, M_0^A + 0.0417\, M_0^B + 250{,}000$$
$$= +250{,}000 \text{ in.} = +\alpha_0^B.$$

Girder Stresses.

Top flange:

$$\text{Max. comp.} = \frac{100}{50} S_0^A - \frac{1}{50} M_0^A + \frac{100}{50} V_0^A - \frac{\overline{w_0 100^2}}{2 \times 50}$$
$$= +23{,}836 \text{ lb} \quad (x = 100 \text{ in.}),$$
$$\text{Max. tens.} = -\tfrac{100}{50} S_0^A + \tfrac{1}{50} M_0^A = +6{,}164 \text{ lb}$$
$$(x = 0 \text{ in.}, \ \epsilon x = 200 \text{ in.}).$$

Bottom flange:

$$\text{Max. tens.} = \frac{150}{50} S_0^A - \frac{1}{50} M_0^A + \frac{100}{50} V_0^A - \frac{\overline{w_0 100^2}}{2 \times 50}$$
$$= +18{,}816 \text{ lb} \quad (x = 100 \text{ in.}),$$
$$\text{Max. comp.} = -\tfrac{100}{50} S_0^A + \tfrac{1}{50} M_0^B = +11{,}814 \text{ lb}$$
$$(x = 0 \text{ in.}, \ \epsilon x = 200 \text{ in.}).$$

Max. Compressive Column Fibre Stress.

$$\text{For Col. } A = \frac{(100\, S_0^A - M_0^A) \times 7.00}{500} + \frac{30{,}000}{15}$$
$$= 4{,}315 + 2{,}000 = +6{,}315 \text{ lb per sq. in.}$$

This occurs at the inside top fibre.

For Col. B.

Same as for Column A.

Checks.

Using the geometrical check of Equation A,

$$\left.\begin{aligned} \delta_0^A + \frac{d_0}{2} C_1^A - \lambda_0^a &= -19{,}235 \text{ in.} \\ \delta_1^B + \frac{d_0}{2} C_1^B &= -20{,}925 \text{ in.} \end{aligned}\right\} \text{Considering the large quantities involved this checks.}$$

The Arch Theory Applied to Portals P_1 and P_2.—As has just been

shown, the effect of the *floor loads* in producing *bending moments* in the columns is very large. These results were so large and considered so important that it was decided to test the theory of

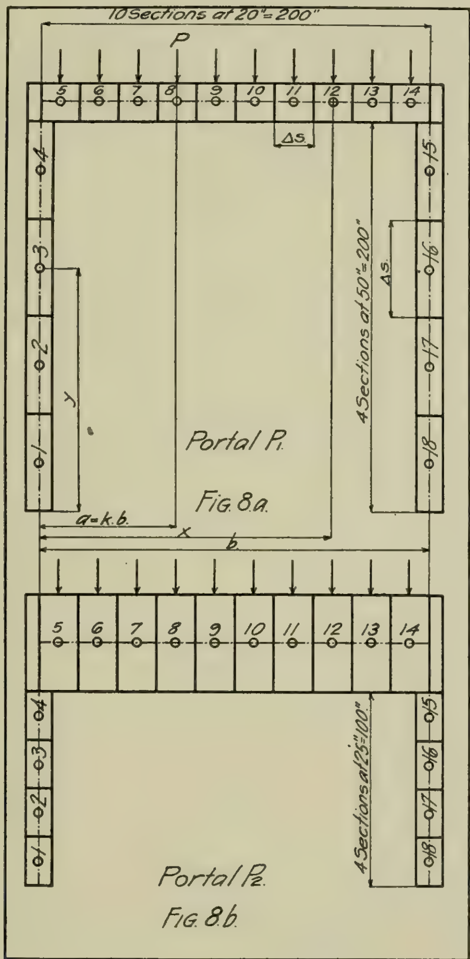


FIG. 8a.

FIG. 8b.

Chapter III by computing the quantities S_0^B, the "thrust of the arch," by the theory so well developed by Professor Howe, for the floor load w_0 only. Adapting his formulae for a fixed arch, to the present case, the value of S_0^B is given thus:

$$S_0^B = \frac{(1-k)\Sigma_0^a \dfrac{xy\Delta s}{I} + k\Sigma_a^b \dfrac{b(b-x)y\Delta s}{I} - \dfrac{(1-k)\Sigma_0^a \dfrac{x\Delta s}{I} + k\Sigma_a^b \dfrac{(b-x)\Delta s}{I}}{\Sigma_0^b \dfrac{\Delta s}{I}} \times \Sigma_0^b \dfrac{y\Delta s}{I}}{\Sigma_0^b \dfrac{y^2\Delta s}{I} - \dfrac{\left(\Sigma_0^b \dfrac{y\Delta s}{I}\right)^2}{\Sigma_0^b \dfrac{\Delta s}{I}}}$$

In which $a = kb$, where k is a decimal fraction, a being the value of x, measured from the left support, corresponding to the single concentrated load producing S_0^B.

In making the calculations the uniform floor load is divided into ten equal parts, each part then being considered as a concentrated load applied at its center of gravity. Figs. 8, a and b, show the subdivisions of the portals for the calculations which are given in the following tables.

Portal P 1.—For Total Uniform Floor Load of 60000 lbs.

Substituting in the equation for S_0^B the values in the tables given on pages 103 and 104 we find:

For load P at 5,

$$S_0^B = P\left\{\frac{0.95\times 35.0 + 0.05\times 2{,}835.0 - (0.95\times 0.1667 + 0.05\times 13.5)\times\dfrac{75.00}{0.5667}}{12{,}599 - \dfrac{(75.00)^2}{0.5667} = 2{,}679}\right\} \doteq 0.0242P.$$

For load P at 6,

$$S_0^B = P\left\{\frac{0.85\times 140.0 + 0.15\times 2{,}240.0 - (0.85\times 0.6667 + 0.15\times 10.667)\times\dfrac{75.00}{0.5667}}{2{,}679}\right\} = 0.0628P.$$

For load P at 7,

$$S_0^B = P\left\{\frac{0.75\times 315.0 + 0.25\times 1{,}715.0 - (0.75\times 1.500 + 0.25\times 8.167)\times\dfrac{75.00}{0.5667}}{2{,}679}\right\} = 0.0920P.$$

PORTAL P_1—FOR TOTAL UNIFORM FLOOR LOAD OF 60,000 POUNDS.

Pt.	x	y	I	Δs	$\Delta s/I$	$y\Delta s/I$	$y^2\Delta s/I$	$xy\Delta s/I$	$x\Delta s/I$
1	0	25	1,000	50	0.050	1.250	31.2	0	0
2	0	75	1,000	50	0.050	3.75	281.5	0	0
3	0	125	1,000	50	0.050	6.25	781.0	0	0
4	0	175	1,000	50	0.050	8.75	1531.0	0	0
5	10	210	1,200	20	0.01667	3.50	735.0	35	0.1667
6	30	210	1,200	20	0.01667	3.50	735.0	105	0.500
7	50	210	1,200	20	0.01667	3.50	735.0	175	0.833
8	70	210	1,200	20	0.01667	3.50	735.0	245	1.167
9	90	210	1,200	20	0.01667	3.50	735.0	315	1.500
10	110	210	1,200	20	0.01667	3.50	735.0	385	1.833′
11	130	210	1,200	20	0.01667	3.50	735.0	455	2.167
12	150	210	1,200	20	0.01667	3.50	735.0	525	2.500
13	170	210	1,200	20	0.01667	3.50	735.0	595	2.833
14	190	210	1,200	20	0.01667	3.50	735.0	665	3.167
15	200	175	1,000	50	0.050	8.75	1531.0	1,750	10.000
16	200	125	1,000	50	0.050	6.25	781.0	1,250	10.000
17	200	75	1,000	50	0.050	3.75	281.5	750	10.000
18	200	25	1,000	50	0.050	1.25	31.2	250	10.000
Σ					0.5667	75.00	12599	7,500	56.667

Pt.	For Load at 5.			For Load at 6.			For Load at 7.			For Load at 8.			For Load at 9.		
	$(b-x)\frac{b}{a}$	$\frac{(b-x)\Delta s}{I}$	$\frac{(b-x)y\Delta s}{I}$	$(b-x)\frac{b}{a}$	$\frac{(b-x)\Delta s}{I}$	$\frac{(b-x)y\Delta s}{I}$	$(b-x)\frac{b}{a}$	$\frac{(b-x)\Delta s}{I}$	$\frac{(b-x)y\Delta s}{I}$	$(b-x)\frac{b}{a}$	$\frac{(b-x)\Delta s}{I}$	$\frac{(b-x)y\Delta s}{I}$	$(b-x)\frac{b}{a}$	$\frac{(b-x)\Delta s}{I}$	$\frac{(b-x)y\Delta s}{I}$
1		$k = 0.05$			$k = 0.15$			$k = 0.25$			$k = 0.35$			$k = 0.45$	
2		$1 - k = 0.95$			$1 - k = 0.85$			$1 - k = 0.75$			$1 - k = 0.65$			$1 - k = 0.55$	
3															
4															
5															
6	170	2.833	595												
7	150	2.500	525	150	2.500	525									
8	130	2.167	455	130	2.167	455	130	2.167	455						
9	110	1.833	385	110	1.833	385	110	1.833	385	110	1.833	385			
10	90	1.500	315	90	1.500	315	90	1.500	315	90	1.500	315	90	1.500	315
11	70	1.167	245	70	1.167	245	70	1.167	245	70	1.167	245	70	1.167	245
12	50	0.833	175	50	0.833	175	50	0.833	175	50	0.833	175	50	0.833	175
13	30	0.500	105	30	0.500	105	30	0.500	105	30	0.500	105	30	0.500	105
14	10	0.167	35	10	0.167	35	10	0.167	35	10	0.167	35	10	0.167	35
15	0	0.000	0	0	0.000	0	0	0.000	0	0	0.000	0	0	0.000	0
16	0	0.000	0	0	0.000	0	0	0.000	0	0	0.000	0	0	0.000	0
17	0	0.000	0	0	0.000	0	0	0.000	0	0	0.000	0	0	0.000	0
18	0	0.000	0	0	0.000	0	0	0.000	0	0	0.000	0	0	0.000	0
Σ		13.500	2835		10.667	2240		8.167	1715		6.000	1260		4.167	875

For load P at 8,

$$S_0^B = P\left\{\frac{\begin{array}{l}0.65\times 560.0+0.35\times 1{,}260.0\\ \quad -(0.65\times 2.667+0.35\times 6.000)\times \dfrac{75.00}{0.5667}\end{array}}{2{,}679}\right\} = 0.1112P.$$

For load P at 9,

$$S_0^B = P\left\{\frac{\begin{array}{l}0.55\times 875.0+0.45\times 875.0\\ \quad -(0.55\times 4.167+0.45\times 4.167)\times \dfrac{75.00}{0.5667}\end{array}}{2{,}679}\right\} = 0.1208P.$$

For all loads on,

$$S_0^B = 2(0.0242 + 0.0628 + 0.0920 + 0.1112 + 0.1208)P$$

$$= 0.8220P = 0.8220 \times \frac{60{,}000}{10} = 4{,}930 \text{ lb}.$$

The value of S_0^B, by the method of Chapter III was found to be 4,680 lb.

The arch formula used does not consider the effect of the axial thrust.

Portal P 2.—For Total Uniform Floor Load of 60000 lbs.

Substituting in the equation for S_0^B the values of the tables on pages 106 and 107 give:

For load P at 5,

$$S_0^B = P\left\{\frac{\begin{array}{l}0.95\times 5.0+0.05\times 405\\ \quad -(0.95\times 0.040+0.05\times 3.240)\times \dfrac{23.750}{0.440}\end{array}}{1{,}859.6 - \dfrac{(23.750)^2}{0.440} = 580}\right\} = 0.0245P.$$

For load P at 6,

$$S_0^B = P\left\{\frac{\begin{array}{l}0.85\times 20.0+0.15\times 320\\ \quad -(0.85\times 0.160+0.15\times 2.560)\times \dfrac{23.750}{0.440}\end{array}}{580}\right\} = 0.0637P.$$

PORTAL P_2 FOR TOTAL UNIFORM FLOOR LOAD OF 60,000 POUNDS.

Pt.	x	y	I	Δs.	$\Delta s/I$.	$y\Delta s/I$.	$y^2\Delta s/I$.	$x\Delta s/I$.	$xy\Delta s/I$.
1	0	12.5	500	25	0.050	0.625	7.8	0.000	0.0
2	0	37.5	500	25	0.050	1.875	70.3	0.000	0.0
3	0	62.5	500	25	0.050	2.500	156.2	0.000	0.0
4	0	87.5	500	25	0.050	4.375	383.0	0.000	0.0
5	10	125.0	5,000	20	0.004	0.500	62.5	0.040	5.0
6	30	125.0	5,000	20	0.004	0.500	62.5	0.120	15.0
7	50	125.0	5,000	20	0.004	0.500	62.5	0.200	25.0
8	70	125.0	5,000	20	0.004	0.500	62.5	0.280	35.0
9	90	125.0	5,000	20	0.004	0.500	62.5	0.360	45.0
10	110	125.0	5,000	20	0.004	0.500	62.5	0.440	55.0
11	130	125.0	5,000	20	0.004	0.500	62.5	0.520	65.0
12	150	125.0	5,000	20	0.004	0.500	62.5	0.600	75.0
13	170	125.0	5,000	20	0.004	0.500	62.5	0.680	85.0
14	190	125.0	5,000	20	0.004	0.500	62.5	0.760	95.0
15	200	87.5	500	25	0.050	4.375	383.0	10.000	875.0
16	200	62.5	500	25	0.050	2.500	156.2	10.000	500.0
17	200	37.5	500	25	0.050	1.875	70.3	10.000	375.0
18	200	12.5	500	25	0.050	0.625	7.8	10.000	125.0
Σ					0.440	23.750	1,859.6	44.000	2,375.0

Pt.	For Load at 5.			For Load at 6.			For Load at 7.			For Load at 8.			For Load at 9.		
	$(b-x)\frac{b}{a}$	$\frac{(b-x)\Delta s}{I}$	$\frac{(b-x)y\Delta s}{I}$	$(b-x)\frac{b}{a}$	$\frac{(b-x)\Delta s}{I}$	$\frac{(b-x)y\Delta s}{I}$	$(b-x)\frac{b}{a}$	$\frac{(b-x)\Delta s}{I}$	$\frac{(b-x)y\Delta s}{I}$	$(b-x)\frac{b}{a}$	$\frac{(b-x)\Delta s}{I}$	$\frac{(b-x)y\Delta s}{I}$	$(b-x)\frac{b}{a}$	$\frac{(b-x)\Delta s}{I}$	$\frac{(b-x)y\Delta s}{I}$
1	$k = 0.05$			$k = 0.15$			$k = 0.25$			$k = 0.35$			$k = 0.45$		
2	$1 - k = 0.95$			$1 - k = 0.85$			$1 - k = 0.75$			$1 - k = 0.65$			$1 - k = 0.55$		
3															
4															
5															
6	170	0.680	85												
7	150	0.600	75	150	0.600	75									
8	130	0.520	65	130	0.520	65	130	0.520	65						
9	110	0.440	55	110	0.440	55	110	0.440	55	110	0.440	55			
10	90	0.360	45	90	0.360	45	90	0.360	45	90	0.360	45	90	0.360	45
11	70	0.280	35	70	0.280	35	70	0.280	35	70	0.280	35	70	0.280	35
12	50	0.200	25	50	0.200	25	50	0.200	25	50	0.200	25	50	0.200	25
13	30	0.120	15	30	0.120	15	30	0.120	15	30	0.120	15	30	0.120	15
14	10	0.040	5	10	0.040	5	10	0.040	5	10	0.040	5	10	0.040	5
15	0	0.000	0	0	0.000	0	0	0.000	0	0	0.000	0	0	0.000	0
16	0	0.000	0	0	0.000	0	0	0.000	0	0	0.000	0	0	0.000	0
17	0	0.000	0	0	0.000	0	0	0.000	0	0	0.000	0	0	0.000	0
18	0	0.000	0	0	0.000	0	0	0.000	0	0	0.000	0	0	0.000	0
Σ		3.240	405		2.560	320		1.960	245		1.440	180		1.000	125

For load P at 7,

$$S_0^B = P\left\{\frac{0.75\times 45.0+0.25\times 245 \\ -\ (0.75\times 0.360+0.25\times 1.960)\times\dfrac{23.750}{0.440}}{580}\right\} = 0.09315P.$$

For load P at 8,

$$S_0^B = P\left\{\frac{0.65\times 80.0+0.35\times 180 \\ -(0.65\times 0.640+0.35\times 1.440)\times\dfrac{23.750}{0.440}}{580}\right\} = 0.11275P.$$

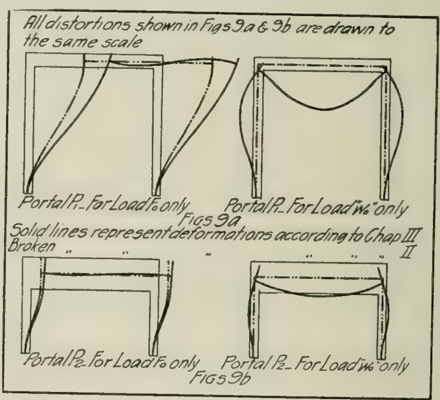
For load P at 9,

$$S_0^B = P\left\{\frac{0.55\times 125.0+0.45\times 125.0 \\ -(0.55\times 1.000+0.45\times 1.000)\times\dfrac{23.750}{0.440}}{580}\right\} = 0.1224P.$$

For all loads on,

$$S_0^B = 2(0.0245 + 0.0637 + 0.09315 + 0.11275 \\ + 0.1224)P = 0.8330P = 0.8330 \times \frac{60{,}000}{10} = 4{,}998 \text{ lb.}$$

The value of S_0^B, by the method of Chapter III, was found to be 5,020 lb.



	For Load F_0.				For Load W_0.			
	Portal P_1.		Portal P_2.		Portal P_1.		Portal P_2.	
	Rigid Gir.	Elastic.	Rigid Gir.	Elastic.	Rigid Gir.	Elastic.	Rigid Gir.	Elastic.
S_0^B	+ 5,000	+ 4,965	+ 5,000	+ 4,915	0	+ 4,680	0	+ 5,020
S_0^A	+ 5,000	+ 5,035	+ 5,000	+ 5,085	0	− 4,680	0	− 5,020
M_0^A	+ 500,000	+ 572,800	+250,000	+268,780	0	−*325,050	0	−†193,800
M_0^B	+ 500,000	+ 566,700	+250,000	+259,220	0	+*325,050	0	+†193,800
X_0^A	100	113.8	50	52.85	0	69.4	0	38.62
X_0^B	100	114.1	50	52.75	0	69.4	0	38.62
H_0	+ 5,000	+ 4,965	+ 5,000	+ 4,915	0	+ 4,680	0	+ 5,020
V_0^A	− 5,500	− 4,802	− 3,750	− 3,610	+ 30,000	+ 30,000	+ 30,000	+ 30,000
V_0^B	+ 5,500	+ 4,802	+ 3,750	+ 3,610	+ 30,000	+ 30,000	+ 30,000	+ 30,000
C_1^A	0	+ 13,807	0	+ 2,860	0	+ 28,554	0	+ 11,425
C_1^B	0	+ 14,090	0	+ 2,740	0	− 28,554	0	− 11,425
δ_0^A	+3,333,333	+4,742,700	+833,333	+992,800	0	− 261,000	0	− 264,700
δ_0^B	+3,333,333	+4,714,000	+833,333	+953,900	0	+ 261,000	0	+ 264,700
Δ_0^a	+ 115,500?	+ 100,900	+ 62,500?	+ 60,167	0	0	0	0
λ_0^a	+ 50,000?	+ 49,650	+ 40,000?	+ 39,320	0	+ 46,800	0	+ 40,160
α_0^A	− 57,750?	− 50,427	− 31,250?	− 30,065	+315,000	+ 315,000	+250,000	+ 250,000
α_0^B	+ 57,750?	+ 50,427	+ 31,250?	+ 30,065	+315,000	+ 315,000	+250,000	+ 250,000
Gir. Str. Top. Flg. +	+ 30,000	+ 26,710	+ 10,000	+ 9,794	75,000	+ 44,450	+ 30,000	+ 23,836
Gir. Str. Top. Flg. −	+ 25,000	+ 21,315	+ 5,000	+ 4,646	0	+ 30,550	0	+ 6,164
Gir. Str. Bott. Flg. +	+ 30,000	+ 26,280	+ 10,000	+ 9,561	0	+ 35,230	0	+ 11,814
Gir. Str. Bott. Flg. −	+ 25,000	+ 21,745	+ 5,000	+ 4,879	75,000	+ 39,770	+ 30,000	+ 18,816
Fib. Str. Col. A	+ 3,225	+ 3,770	+ 3,250	+ 3,522	+ 1,500	+ 5,777	+ 2,000	+ 6,315
Fib. Str. Col. B	+ 3,775	+ 4,207	+ 3,750	+ 3,870	+ 1,500	+ 5,777	+ 2,000	+ 6,315

? These quantities given for comparison only. They can not exist under the assumptions of Chapter II.

* Maximum occurs at top and equals 610,800 inch pounds.

† Maximum occurs at top and equals 308,200 inch pounds.

Thus the arch theory checks the methods developed in Chapter III very nicely. The table on page 109 shows a comparison of the stresses and deformations for the cases worked out in this chapter. In addition to this table, Figs. 9, *a* and *b* (page 108), are drawn to scale to compare the deformations of the structure.

CHAPTER VI.

A STUDY OF THE EFFECT OF WIND PRESSURE ON AN ELASTIC PORTAL BRACED BUILDING — WITH COMPARISONS.

The five story, two column, structure designed in Chapter II is now to be investigated in this and the three succeeding chapters by the methods of Chapter III. As was mentioned in that chapter and demonstrated in Chapter V, for any given structure the symbolic coefficients, with the exception of "z," and the solution of Plate 17, with the exception of the fourth column, are entirely independent of the loading. Therefore, by providing only a few extra columns in the tables of this chapter the values of the symbolic coefficients and the solution of Plate 17 may be most conveniently given here for all the loadings. The calculations for eccentric column loads alone (Chapter IX) will be made by combining the calculations of Chapter VII and VIII. These tables in this chapter then will provide for the following loadings:

(*a*) Wind load only on face A.

(*b*) Floor and eccentric column loads combined.

(*c*) Floor loads only.

Wind loads will be taken as used in the design, Chapter II.

Floor loads will here be taken as uniformly distributed over the girders instead of being concentrated at the beam connections. They will be considered as extending only to the centres of the columns and the unit floor loads of Chapter II will be used.

Eccentric column loads and their eccentricities will be taken as given in Chapter II, exclusive of the floor loads and weight of columns and fireproofing.

The structure will be computed first by the methods of Chapter III; then a comparison will be made with the results by the methods of Chapter II for which, of course, the loadings as modified above are to be used.

The properties of the structure and the values of the loads are as given in the following table.

		Stories. 0	1	2	3	4
	c	125.0	125.0	125.0	125.0	130.0
	d	25.0	25.0	25.0	25.0	20.0
	b	200.0	200.0	200.0	200.0	200.0
	I^A	1,550.9	1,550.9	878.6	878.6	461.0
	I^B	1,550.9	1,122.6	1,122.6	660.8	660.8
	I^a	2,740.0	2,378.0	1,972.0	1,850.0	1,041.0
	A^A	34.73	34.73	19.73	19.73	11.52
	A^B	34.73	24.65	24.65	15.23	15.23
	A^a	23.67	20.33	17.77	17.00	14.47
	P^A	23,500	23,500	23,500	23,500	12,500
	P^B	31,225	31,225	31,225	31,225	0
	e^A	10.75	10.75	10.75	10.75	10.75
	e^B	4.50	4.50	4.50	4.50	4.50
	w	*353.35	*233.75	*233.75	*233.75	200.00
	F	3,750	7,500	7,500	7,500	6,750
	ΣF	33,000	29,250	21,750	14,250	6,750
Wind load	X	+15,354,375	+10,451,250	+ 6,157,500	+2,988,750	+ 945,000
	Y	0	0	0	0	0
Floor and column loads	X	−46,974,835	−35,095,720	−25,608,605	−16,121,490	−6,634,375
	Y	+ 482,320	+ 356,925	+ 255,450	+ 153,975	+ 52,500
Floor loads	X	−25,092,000	−18,025,000	−13,350,000	− 8,675,000	−4,000,000
	Y	+ 250,920	+ 180,250	+ 133,500	+ 86,750	+ 40,000

* These quantities should have been 350.00 and 233.33 respectively.

Using the quantities in the above table the values of the symbolic coefficients as given in Plate 15 are as follows:

Values of the Symbolic Coefficients.

a_1	a_2	a_3	a_4	b_0	b_1	b_2	b_3	b_4
+0.080598	+0.14227	+0.14227	+0.28200	0	0	0	0	0
0	0	0	0	+0.080598	+0.11135	+0.11135	+0.18917	+0.19673
+5.0374	+8.8920	+8.8920	+18.330	0	0	0	0	0
0	0	0	0	+5.0374	+6.9593	+6.9593	+11.823	+12.788
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
+0.005	+0.005	+0.005	+0.005	+0.005	+0.005	+0.005	+0.005	+0.005
−0.005	−0.005	−0.005	−0.005	−0.005	−0.005	−0.005	−0.005	−0.005
+0.02160	+0.03800	+0.03800	+0.06614	+0.019795	+0.02160	+0.03800	+0.03800	+0.06614
−0.03042	−0.03042	−0.04926	−0.05010	−0.019795	−0.03042	−0.03042	−0.04926	−0.05010
−0.05202	−0.06842	−0.08726	−0.11624	−0.03959	−0.05202	−0.06842	−0.08726	−0.11624
−0.0004205	−0.0005072	−0.0005405	−0.0009600	0	0	0	0	0
+0.000002102	+0.000002536	+0.000002702	+0.000004800	+0.000001825	+0.000002102	+0.000002536	+0.000002702	+0.000004800
+6.044	+10.669	+10.669	+21.150	−6.044	−8.350	−8.350	−14.186	−14.755
−0.12265	−0.19299	−0.19632	−0.37800	+0.11710	+0.15340	+0.16207	+0.24322	+0.29273
−2.751	−3.313	−3.516	−6.284	+21.027	+27.927	+29.101	+45.126	+52.262

Values in the Transformed Equations.

a_1	a_2	a_3	a_4	b_0	b_1	b_2	b_3	b_4
+0.080598	+0.14227	+0.14227	+0.28200	0	0	0	0	0
0	0	0	0	+0.080598	+0.11135	+0.11135	+0.18917	+0.19673
−0.05202	−0.06842	−0.08726	−0.11624	−0.03959	−0.05202	−0.06842	−0.08726	−0.11624
+6.044	+10.669	+10.669	+21.150	−6.044	−8.350	−8.350	−14.186	−14.755
−0.12265	−0.19299	−0.19632	−0.37800	+0.11710	+0.15340	+0.16207	+0.24322	+0.29273
−2.751	−3.313	−3.516	−6.284	+21.027	+27.927	+29.101	+45.126	+52.262

Values in the Final Simplified Equations.

a_1	a_2	a_3	a_4	b_0	b_1	b_2	b_3	b_4
+0.61450	+0.94810	+0.90705	+1.5301	−0.71545	−0.84890	−0.74200	−1.2060	−1.0675
+4.8520	+6.6316	+6.2884	+6.8894	+2.2246	+2.6666	+2.2162	+3.5239	+2.0662
+1.9353	+2.8259	+2.6563	+2.9538	+5.4329	+6.3146	+5.4122	+8.0236	+5.1142

n.	e_0	e_1	e_2	e_3	e_4	f_0	f_1	f_2	f_3	f_4
	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0
	+0.0003650	+0.0004205	+0.0005072	+0.0005405	+0.0009600	0	0	0	0	0
	−0.000001825	−0.000002102	−0.000002536	−0.000002702	−0.000004800	−0.000001825	−0.000002102	−0.000002536	−0.000002702	−0.000004800
	0	0	0	0	0	0	0	0	0	0
	+0.03650	+0.04205	+0.05072	+0.05405	+0.09600	−0.03650	−0.04205	−0.05072	−0.05405	−0.09600
	+2.433	+2.803	+3.381	+3.603	+6.400	−4.866	−5.606	−6.762	−7.206	−12.800

Values in the Transformed Equations.

	e_0	e_1	e_2	e_3	e_4	f_0	f_1	f_2	f_3	f_4
	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0
	+0.03650	+0.04205	+0.05072	+0.05405	+0.09600	−0.03650	−0.04205	−0.05072	−0.05405	−0.09600
	+2.433	+2.803	+3.381	+3.603	+6.400	−4.866	−5.606	−6.762	−7.206	−12.800

Values in the Final Simplified Equations.

	e_0	e_1	e_2	e_3	e_4	f_0	f_1	f_2	f_3	f_4
	0	0	0	0	0	0	0	0	0	0
	+1.0	+1.0	+1.0	+1.0	+1.0	0	0	0	0	0
	0	0	0	0	0	+1.0	+1.0	+1.0	+1.0	+1.0

Exp'n.	i_0	i_1	i_2	i_3	i_4	l_0	l_1	l_2	l_3	l_4
$C-A$	− 5.0374	− 5.0374	− 8.8920	− 8.8920	− 18.330	0	0	0	0	0
$C-B$	+ 5.0374	+ 6.9593	+ 6.9593	+ 11.823	+ 12.788	0	0	0	0	0
$\delta-A$	− 210.0	− 210.0	− 371.0	− 371.0	− 795.0	0	0	0	0	0
$\delta-B$	+ 210.0	+ 290.0	+ 290.0	+ 493.0	+ 554.0	0	0	0	0	0
$H-a$	− 1.0	− 1.0	− 1.0	− 1.0	− 1.0	+ 1.0	+ 1.0	+ 1.0	+ 1.0	+ 1.0
$\lambda-a$	− 8.450	− 9.845	− 11.255	− 11.760	− 13.825	+ 8.450	+ 9.845	+ 11.255	+ 11.760	+ 13.825
$V-A$	0	0	0	0	0	0	0	0	0	0
$V-B$	0	0	0	0	0	0	0	0	0	0
$\alpha-A$	0	0	0	0	0	0	0	0	0	0
$\alpha-B$	0	0	0	0	0	0	0	0	0	0
$\Delta-a$	0	0	0	0	0	0	0	0	0	0
$Q-a$	+ 0.05020	+ 0.05780	+ 0.06975	+ 0.07435	+0.13440	+ 0.004565	+ 0.005250	+ 0.006340	+ 0.006750	+ 0.009600
$R-a$	0	0	0	0	0	0	0	0	0	0
$A-a$	− 537.5	− 631.7	− 838.0	−1099.9	−1634.6	− 8.450	− 9.845	− 11.255	− 11.760	− 13.825
$B-a$	+ 20.114	+ 23.557	+ 29.801	+ 35.585	+ 57.998	+ 0.9130	+ 1.0500	+ 1.2680	+ 1.3500	+ 1.9200
$C-a$	+2011.48	+2547.86	+2786.86	+3851.6	+5245.6	+ 91.30	+105.00	+126.80	+135.00	+192.00

Values in the Transformed Equations.

Exp'n.	i_0	i_1	i_2	i_3	i_4	l_0	l_1	l_2	l_3	l_4
$C-A$	+ 5.0374	+ 5.0374	+ 8.8920	+ 8.8920	+ 18.330	0	0	0	0	0
$C-B$	− 5.0374	− 6.9593	− 6.9593	− 11.823	− 12.788	+ 0	0	0	0	0
$\Delta-a$	0	0	0	0	0	0	0	0	0	0
$A-a$	+ 545.94	+ 649.98	+ 859.09	+1122.93	+1660.18	− 8.450	− 9.845	− 11.255	− 11.760	− 13.825
$B-a$	− 21.027	− 24.607	− 31.069	− 36.935	− 59.918	− 0.9130	+ 1.0500	+ 1.2680	+ 1.3500	+ 1.9200
$C-a$	−2102.8	−2652.9	−2913.7	−3986.6	−5437.6	+ 91.30	+105.00	+126.80	+135.00	+192.00

Values in the Final Simplified Equations.

Exp'n.	i_0	i_1	i_2	i_3	i_4	l_0	l_1	l_2	l_3	l_4
$A-a$	+ 64.585	+ 66.055	+ 76.285	+ 95.380	+ 120.070	+ 1.0	+ 1.0	+ 1.0	+ 1.0	+ 1.0
$B-a$	+ 288.03	+ 224.08	+ 363.46	+ 260.29	+ 398.51	− 12.500	− 12.500	− 12.500	− 12.500	− 10.00
$C-a$	− 288.03	− 361.21	− 249.13	− 422.98	− 225.44	+ 12.500	+ 12.500	+ 12.500	+ 12.500	+ 10.00

Exp'n.	s_0	s_1	s_2	s_3	s_4	t_0	t_1	t_2	t_3	t_4
$C-A$	+ 1.0	+ 1.0	+ 1.0	+ 1.0	+ 1.0	0	0	0	0	0
$C-B$	0	0	0	0	0	+ 1.0	+ 1.0	+ 1.0	+ 1.0	+ 1.0
$\delta-A$	+ 125.0	+ 125.0	+ 125.0	+ 125.0	+ 130.0	0	0	0	0	0
$\delta-B$	0	0	0	0	0	+125.0	+125.0	+125.0	+125.0	+130.0
$H-a$	0	0	0	0	0	0	0	0	0	0
$\lambda-a$	0	0	0	0	0	0	0	0	0	0
$V-A$	0	0	0	0	0	0	0	0	0	0
$V-B$	0	0	0	0	0	0	0	0	0	0
$\alpha-A$	0	0	0	0	0	0	0	0	0	0
$\alpha-B$	0	0	0	0	0	0	0	0	0	0
$\Delta-a$	0	0	0	0	0	0	0	0	0	0
$Q-a$	0	0	0	0	0	0	0	0	0	0
$R-a$	0	0	0	0	0	0	0	0	0	0
$A-a$	+ 137.5	+ 150.0	+ 150.0	+ 150.0	+ 152.5	−137.5	−150.0	−150.0	−150.0	−152.5
$B-a$	− 1.0	− 1.0	− 1.0	− 1.0	− 1.0	+ 1.0	+ 1.0	+ 1.0	+ 1.0	+ 1.0
$C-a$	0	0	0	0	0	+200.0	+200.0	+200.0	+200.0	+200.0

Values in the Transformed Equations.

Exp'n.	s_0	s_1	s_2	s_3	s_4	t_0	t_1	t_2	t_3	t_4
$C-A$	+ 1.0	+ 1.0	+ 1.0	+ 1.0	+ 1.0	0	0	0	0	0
$C-B$	0	0	0	0	0	+ 1.0	+ 1.0	+ 1.0	+ 1.0	+ 1.0
$\Delta-a$	0	0	0	0	0	0	0	0	0	0
$A-a$	+ 137.5	+ 150.0	+ 150.0	+ 150.0	+ 152.5	−137.5	−150.0	−150.0	−150.0	−152.5
$B-a$	− 1.0	− 1.0	− 1.0	− 1.0	− 1.0	+ 1.0	+ 1.0	+ 1.0	+ 1.0	+ 1.0
$C-a$	0	0	0	0	0	+200.0	+200.0	+200.0	+200.0	+200.0

Values in the Final Simplified Equations.

Exp'n.	s_0	s_1	s_2	s_3	s_4	t_0	t_1	t_2	t_3	t_4
$A-a$	0	+ 15.247	+ 13.328	+ 12.750	+ 11.034	0	− 15.247	− 13.328	− 12.750	− 11.034
$B-a$	+ 54.800	+ 47.560	+ 39.440	+ 37.000	+ 20.820	+ 27.400	+ 23.780	+ 19.720	+ 18.500	+ 10.410
$C-a$	+ 27.400	+ 23.780	+ 19.720	+ 18.500	+ 10.410	+ 54.800	+ 47.560	+ 39.440	+ 37.000	+ 20.820

Exp'n.	w_0	w_1	w_2	w_3	w_4	P_0	P_1	P_2	P_3	P_4
$C-A$	0	0	0	0	0	0	0	0	0	0
$C-B$	0	0	0	0	0	0	0	0	0	0
$\delta-A$	0	0	0	0	0	0	0	0	0	0
$\delta-B$	0	0	0	0	0	0	0	0	0	0
$H-a$	0	0	0	0	0	0	0	0	0	0
$\lambda-a$	0	0	0	0	0	0	0	0	0	0
$V-A$	0	0	0	0	0	0	0	0	0	0
$V-B$	0	0	0	0	0	0	0	0	0	0
$\alpha-A$	0	0	0	0	0	0	0	0	0	0
$\alpha-B$	0	0	0	0	0	0	0	0	0	0
$\Delta-a$	0	+ 1.0	+ 1.0	+ 1.0	+ 1.0	0	0	0	0	0
$Q-a$	0	0	0	0	0	0	0	0	0	0
$R-a$	0	0	0	0	0	0	0	0	0	0
$A-a$	0	0	0	0	0	0	0	0	0	0
$B-a$	0	0	0	0	0	0	− 8.450	− 9.845	− 11.255	− 11.760
$C-a$	0	− 1.0	− 1.0	− 1.0	− 1.0	0	0	0	0	0
				VALUES IN THE TRANSFORMED EQUATIONS.						
$C-A$	0	0	0	0	0	0	0	0	0	0
$C-B$	0	0	0	0	0	0	0	0	0	0
$\Delta-a$	0	+ 1.0	+ 1.0	+ 1.0	+ 1.0	0	0	0	0	0
$A-a$	0	0	0	0	0	0	+ 8.450	+ 9.845	+ 11.255	+ 11.760
$B-a$	0	0	0	0	0	0	0	0	0	0
$C-a$	0	− 1.0	− 1.0	− 1.0	− 1.0	0	0	0	0	0
				VALUES IN THE FINAL SIMPLIFIED EQUATIONS.						
$A-a$	0	0	0	0	0	0	+ 0.85890	+ 0.87405	+ 0.95665	+ 0.85120
$B-a$	− 0.41100	− 0.35670	− 0.29580	− 0.27750	− 0.15615	0	0	0	0	0
$C-a$	− 0.41100	− 0.35670	− 0.29580	− 0.27750	− 0.15615	0	0	0	0	0

Exp'n.	For Wind on Face *A* Only. z_0	z_1	z_2	z_3	z_4	For Floor and Eccentric Column Loads. z_0	z_1	z_2	z_3	z_4
$C-A$	0	0	0	0	0	0	0	0	0	0
$C-B$	− 166,300	− 203,500	− 151,300	− 168,500	− 86,350	0	0	0	0	0
$\delta-A$	0	0	0	0	0	0	0	0	0	0
$\delta-B$	− 6,930,000	− 8,485,000	− 6,315,000	− 7,030,000	− 3,740,000	0	0	0	0	0
$H-a$	+ 3,750	+ 7,500	+ 7,500	+ 7,500	+ 6,750	0	0	0	0	0
$\lambda-a$	+ 31,670	+ 73,800	+ 84,450	+ 88,250	+ 93,250	0	0	0	0	0
$V-A$	− 76,772	− 52.256	− 30,788	− 14,944	− 4,725	+ 234,874	+ 175,479	+ 128,043	+ 80,607	+ 33,172
$V-B$	+ 76,772	+ 52,256	+ 30,788	+ 14,944	+ 4,725	+ 247,446	+ 181,446	+ 127,407	+ 73,368	+ 19,328
$\alpha-A$	− 303,950	− 225,680	− 234,000	− 113,600	− 62,500	+ 930,270	+ 758,000	+ 973,230	+ 613,000	+ 439,120
$\alpha-B$	+ 303,900	+ 318,000	+ 187,400	+ 147,210	+ 47,350	+ 979,500	+1,104,290	+ 775,000	+ 722,700	+ 193,500
$\Delta-a$	+ 607,850	+ 543,680	+ 421,400	+ 260,810	+ 109,850	+ 49,770	+ 346,290	− 198,230	+ 109,700	− 245,620
$Q-a$	0	0	0	0	0	− 92.20	− 106.3	− 128.1	− 136.6	− 129.0
$R-a$	− 8.945	− 9.030	− 8.030	− 5.525	− 4.535	+ 13.10	+ 10.07	+ 12.14	+ 12.94	+ 19.8
$A-a$	+ 8,977,080	+10,986,620	+ 8,195,600	+ 9,132,450	+ 4,598,500	0	0	0	0	0
$B-a$	− 345,200	− 384,100	− 311,900	− 279,000	− 177,050	+ 71,760	+ 49,040	+ 59,180	+ 62,980	+ 115,200
$C-a$	−57,721,100	−65,323,700	−52,094,700	−48,694,100	−29,473,100	+7,269,200	+4,716,000	+6,309,500	+6,390,000	+12,195,600
Values in the Transformed Equations.										
$C-A$	− 166,300	− 147,400	− 193,400	− 126,700	− 123,700	0	0	0	0	0
$C-B$	0	0	0	0	0	0	0	0	0	0
$\Delta-a$	+ 607,850	+ 543,680	+ 421,400	+ 260,810	+ 109,850	+ 49,770	+ 346,290	− 198,230	+ 109,700	− 245,620
$A-a$	− 9,011,300	− 7,971,200	−10,483,700	− 6,863,700	− 6,596,700	0	0	0	0	0
$B-a$	+ 345,290	+ 327,750	+ 354,350	+ 237,200	+ 214,450	+ 71,760	+ 49,040	+ 59,180	+ 62,980	+ 115,200
$C-a$	+11,328,900	+11,485,300	+10,326,300	+ 7,100,900	+ 5,935,900	+7,269,200	+4,716,000	+6,309,500	+6,390,000	+12,195,600
Values in the Final Simplified Equations.										
$A-a$	− 1,065,700	− 811,350	− 930,800	− 583,400	− 477,450	0	0	0	0	0
$B-a$	−14,262,545	−11,496,090	−10,921,410	− 6,804,722	− 3,538,554	− 945,664	− 650,072	− 467,902	− 556,984	− 493,937
$C-a$	− 4,804,620	− 3,698,140	− 3,938,660	− 2,416,672	− 1,305,354	+1,016,865	+ 515,125	+ 697,295	+ 608,213	+ 705,022

FOR FLOOR LOADS ONLY.

	z_0	z_1	z_2	z_3	z_4
C–A	0	0	0	0	0
C–B	0	0	0	0	0
δ–A	0	0	0	0	0
δ–B	0	0	0	0	0
H–A	0	0	0	0	0
λ–a	0	0	0	0	0
V–A	+ 125,460	+ 90,125	+ 66,750	+ 43,375	+ 20,000
V–B	+ 125,460	+ 90,125	+ 66,750	+ 43,375	+ 20,000
α–A	+ 496,300	+ 389,000	+ 507,800	+ 330,000	+ 264,700
α–B	+ 496,300	+ 548,180	+ 406,500	+ 427,442	+ 200,200
Δ–a	0	+ 159,180	− 101,300	+ 97,442	− 64,500
R–a	0	0	0	0	0
Q–a	+ 12.90	+ 9.825	+ 11.85	+ 12.64	+ 19.22
A–a	0	0	0	0	0
B–a	+ 86,200	+ 65,400	+ 79,000	+ 84,300	+ 128,200
C–a	+8,630,000	+6,242,500	+8,001,300	+8,334,300	+12,887,800
C–A	0	0	0	0	0
C–B	0	0	0	0	0
Δ–a	0	+ 159,180	− 101,300	+ 97,442	− 64,500
A–a	0	0	0	0	0
B–a	+ 86,200	+ 65,400	+ 79,000	+ 84,300	+ 128,200
C–a	+8,630,000	+6,242,500	+8,001,300	+8,334,300	+12,887,800
A–a	0	0	0	0	0
B–a	−1,177,833	− 835,947	− 749,205	− 806,207	− 656,596
C–a	+1,177,833	+ 722,387	+ 809,129	+ 752,127	+ 676,738

The solution corresponding to Plate 17, for all loadings is now given in the following tables. The tables give the results of every slide rule calculation and, as will be seen, the results are quite accurate. A Thacher rule was used for all these calculations.

For the O Story.

							For Wind on Face A Only.		For Floor and Ec. Col. Loads.		For Floor Loads Only.	
A_0	+350.85 −206.06	+0.99233 +1.4233	B_0		C_0	+5.5757 −1.9894	D_0	+6,362,500 −2,120,000	D_0		D_0	+525,330 0
den.	+144.79	+2.4156		+0.44605		+3.5863		+4,242,500		+421,780		+525,330
A_0'	+143.67 +206.06	+1.0033 −0.58923	B_0'		C_0'	−2.3085 +0.82362	D_0'	+887,250 +877,750	D_0'		D_0'	−217,490 0
den.	+349.73	+0.4141		+0.18467		−1.4849		+1,765,000		−187,760		−217,490
		$A_0-A_0'=+2.0015$										
α_0		−1.7921 −0.74202	β_0		γ_0		δ_0	+2,130,100 − 877,800	δ_0	−226,600 − 87,265	δ_0	−262,490 −108,680
		−2.5341		−0.092290		+0.22288		+1,252,300		−313,865		−371,170
α_0'		+2.5337	β_0'	+0.22285	γ_0'	−0.092265	δ_0'	+1,237,800	δ_0'	+304,530	δ_0'	+371,110
		$\alpha_0+\alpha_0'=-0.0004$		$\beta_0+\beta_0'=+0.13056$		$\gamma_0+\gamma_0'=+0.13062$		$\delta_0+\delta_0'=+2,490,100$				$\delta_0+\delta_0'=-60$
α_0''		+0.0154835 +0.028072 +0.028068	β_0''	+0.0010224 +0.0024688	γ_0''	−0.0024690 −0.0010222	δ_0''	+16,502 −13,873 +13,713	δ_0''	0 +3,477.1 +3,373.5	δ_0''	0.0 +4,112.0 +4,111.2
$\alpha_0''-1=-0.928376$		+0.071624		+0.0034912		−0.0034912		+16,342		+6,850.6		+8,223.2
α_0'''		−0.20424 +0.36081	β_0'''	−0.0074385 +0.017588	γ_0'''	+0.017964 −0.017588	δ_0'''	−166,234 +100,930 + 82,325	δ_0'''	0 −25,296 +34,509	δ_0'''	0 −29,916 +41,424
		+0.15657		+0.010150		+0.000376		+17,021		+9,213		+11,508
α_0^{iv}		+0.20420 −0.36081	β_0^{iv}	+0.017962 −0.017588	γ_0^{iv}	−0.0074363 +0.017588	δ_0^{iv}	+99,765 −82,325	δ_0^{iv}	+24,544 −34,509	δ_0^{iv}	0 +29,912 −41,424
		−0.15661		+0.000374		+0.010152		+17,440		−9,965		−11,512
		$\alpha_0'''-\alpha_0^{iv}=+0.31318$		$\beta_0'''-\beta_0^{iv}=+0.009776$		$\gamma_0'''-\gamma_0^{iv}=-0.009776$		$\delta_0'''-\delta_0^{iv}=-419$				$\delta_0'''-\delta_0^{iv}=+23,020$

For the O Story.—*Continued.*

						For Wind on Face A Only.		For Floor and Ec. Col. Loads.		For Floor Loads Only.	
α_0^{v}	+0.0000158	β_0^{v}	−0.0051687	γ_0^{v}	−0.0051710	δ_0^{v}	+607,850 − 98,590 +509,260	δ_0^{v}	+49,770 + 370 +50,140	δ_0^{v}	0 +2.4 +2.4
θ_0	−4.6765 +0.15657 −4.5199	ϕ_0	+0.080598 +0.017588 +0.010150 +0.108336	ψ_0	−0.017588 +0.000376 −0.017212	ω_0	−147,344 + 82,325 + 17,021 −47,998	ω_0	0 +34,509 + 9,213 +43,722	ω_0	0 +11,508 +41,424 +52,932
θ_0'	+6.4608 −0.15661 +6.3042	ϕ_0'	−0.024297 +0.000374 −0.023923	ψ_0'	+0.11135 +0.024297 +0.010152 +0.14580	ω_0'	−113,720 + 17,440 −96,280	ω_0'	−47,672 −9,965 −57,637	ω_0'	0 −11,512 −57,228 −68,740
θ_0''	+0.0000158	ϕ_0''	−0.052023 −0.0051687 −0.057192	ψ_0''	−0.052023 −0.0051710 −0.057194	ω_0''	+543,680 +509,260 +1,052,940	ω_0''	+346,290 + 50,140 +396,430	ω_0''	+159,180 + 2.4 +159,182.4

For the First Story.

c_1	−61.325 + 4.7750 + 0.8589 −55.691	a_1	+0.61450 +0.23061 +0.14905 +0.99416	b_1	−0.84890 −0.23061 −0.14905 +0.99416	d_1	− 811,350 +1,079,400 − 6,389 +261,661	d_1	0 +452,510 +292,410 +744,920	d_1	0 +543,220 +351,000 +894,220
i_1	−208.03 + 7.447 − 3.724 − 0.000 −204.31	g_1	+4.8520 +0.78233 +0.48272 +0.00889 +0.00184 +6.1278	h_1	+2.6666 −0.78233 +0.01788 +0.24141 +0.00184 +2.1454	k_1	+11,496,090 − 3,662,100 − 809,600 − 414,750 + 181,650 +6,791,290	k_1	+ 650,072 −1,535,100 − 438,160 + 236,970 + 17,885 −1,068,333	k_1	+ 835,947 −1,842,700 − 547,350 + 273,775 + 1 −1,280,327

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For the First Story.—*Continued.*

							For Wind on Face A Only.		For Floor and Ec. Col. Loads.		For Floor Loads Only.	
p_1		+335.340	n_1	+1.9353	o_1	+6.3146	q_1	+3,698,140	q_1	− 515,125	q_1	− 722,387
		+ 3.724		−1.2611		+1.2611		+5,903,200		+2,474,600		+2,970,300
		− 7.449		+0.24136		+0.00894		− 404,800		− 219,080		− 273,675
		0.000		+0.01779		+0.48282		− 829,500		+ 473,940		+ 547,550
				+0.00184		+0.00184		+ 181,650		+ 17,885		+ 1
		+331.62		+0.9352		+8.0693		+8,548,690		+2,232,220		+2,521,789
A_1		+0.86495	B_1		C_1	+5.0393	D_1	+2,737,800	D_1	− 430,630	D_1	− 516,070
	−341.27	+1.8172				−1.4790		+ 387,000		+1,101,600		+1,322,400
	+203.12											
den.	−138.15	+2.6821	$A_1 - A_1' = +2.5723$	+0.40314		+3.5603		+3,124,800		+670,970		+806,330
A_1'		+1.1771	B_1'		C_1'	−1.8235	D_1'	+1,247,100	D_1'	+325,630	D_1'	+367,880
	− 52.083	−1.0673				+0.86872		− 227,300		−647,100		−776,780
	−329.69											
den.	−381.77	+0.1098		+0.14588		−0.9548		+1,019,800		−321,470		−408,900
α_1		−0.99550	β_1		γ_1		δ_1	+1,063,300	δ_1	−335,180	δ_1	−426,340
		−0.15198						− 133,390		− 28,641		− 34,419
		−1.14748		−0.017209		+0.15211		+929,910		−363,821		−460,759
α_1'			β_1'		γ_1'		δ_1'		δ_1'		δ_1'	
		+1.7552		+0.15671		−0.056710		+818,370		+385,820		+472,400
α_1''		−0.017955	β_1''	−0.0003072	γ_1''	+0.0027155	δ_1''	+ 4,698.3	δ_1''	+13,375	δ_1''	+16,056
		−0.020484		−0.0034571		+0.0012510		+16,600.0		− 6,494.5		− 8,225.0
		−0.038722						−18,053.0		− 8,512.2		−10,422.0
$\alpha_1'' - 1 = -0.922839$		−0.077161		−0.0037643		+0.0039665		+3,245		−1,631.7		−2,591

For the First Story.—*Continued.*

						For Wind on Face A Only.		For Floor and Ec. Col. Loads.		For Floor Loads Only.	
α_1'''	$+0.34876$ -0.12434 -0.030211	β_1'''	$+0.017014$ -0.0018644 -0.0026972	γ_1'''	-0.017929 $+0.016481$ $+0.0009761$	δ_1'''	$-14,667$ $+100,750$ $-14,085$ $-47,998$	δ_1'''	$+7,374.8$ $-39,418.0$ $-6,641.2$ $+43,722.0$	δ_1'''	$+52,932$ $+11,712$ $-49,925$ $-8,132.0$
	$+0.19421$		$+0.012452$		-0.000472		$+24,000$		$+5,037.6$		$+6,587$
α_1^{iv}	-0.48643 $+0.027456$ $+0.25591$	β_1^{iv}	-0.023730 $+0.0004117$ $+0.022850$	γ_1^{iv}	$+0.025006$ -0.0036392 -0.0082680	δ_1^{iv}	$+20,457$ $-22,247$ $+119,310$ $-96,280$	δ_1^{iv}	$-10,286$ $+8,703.5$ $+56,255$ $-57,637$	δ_1^{iv}	$-68,740$ $-16,335$ $+11,023$ $+68,883$
	-0.20306		-0.000468		$+0.013099$		$+21,240$		$-2,964.5$		$-5,169$
	$\alpha_1'''-\alpha_1^{iv}=+0.39727$		$\beta_1'''-\beta^{iv}=+0.012920$		$\gamma_1'''-\gamma^{iv}=-0.013571$		$\delta_1'''-\delta_1^{iv}=+2,760$				$\delta_1'''-\delta_1^{iv}=+11,756$
α_1^{v}	-0.0000012 $+0.065625$ -0.10040	β_1^{v}	-0.000000059 $+0.00098420$ -0.00896350	γ_1^{v}	$+0.000000063$ -0.0087000 $+0.0032435$	δ_1^{v}	$+0.1$ $-53,180$ $-46,802$ $+1,052,940$	δ_1^{v}	0 $+20,806$ $-22,067$ $+396,430$	δ_1^{v}	$+159,182$ 0 $+26,351$ $-27,020$
	-0.034776		-0.00797936		-0.0054566		$+952,958$		$+395,169$		$+158,513$
α_1^{vi}	$+0.071637$ -0.0040065 -0.0061283	β_1^{vi}	$+0.0034947$ -0.00006008 -0.00054712	γ_1^{vi}	-0.0036825 $+0.00053105$ $+0.00019798$	δ_1^{vi}	$-3,012.6$ $+3,246.4$ $-2,857.0$ $+16,342.0$	δ_1^{vi}	$+1,514.8$ $-1,270.1$ $-1,347.0$ $+6,850.6$	δ_1^{vi}	$+8,223.2$ $+2,405.4$ $-1,608.6$ $-1,649.4$
$\alpha_1^{vi}-1=-0.938498$	$+0.061502$		$+0.0028875$		-0.0029535		$+13,719$		$+5,748.3$		$+7,370.6$
θ_1	-8.3455 $+0.19421$	ϕ_1	$+0.14227$ $+0.025675$ $+0.012452$	ψ_1	-0.026262 -0.000472	ω_1	$-193,401$ $+121,990$ $+24,000$	ω_1	0 $+51,113$ $+5,037.6$	ω_1	0 $+6,587$ $+65,541$
	-8.1513		$+0.18040$		-0.026734		$-47,411$		$+56,151$		$+72,128$
θ_1'	$+6.5312$ -0.20306	ϕ_1'	-0.020093 -0.000468	ψ_1'	$+0.11135$ $+0.020553$ $+0.013099$	ω_1'	$-95,470$ $+21,240$	ω_1'	$-40,003$ $-2,964.5$	ω_1'	$-5,169$ $-52,190$
	$+6.3281$		-0.020561		$+0.14500$		$-74,230$		$-42,968$		$-56,459$
θ_1''		ϕ_1''	-0.068442 -0.0079794	ψ_1''	-0.068442 -0.0054566	ω_1''	$+421,400$ $+952,958$	ω_1''	$-198,230$ $+395,169$	ω_1''	$-101,300$ $+158,513$
	-0.034776		-0.076421		-0.073899		$+1,374,358$		$+196,939$		$+57,213$

For the Second Story

							For Wind on Face A Only.		For Floor and Ec. Col. Loads.		For Floor Loads Only.	
c_2		−71.598	a_2	+0.94810	b_2	−0.74200	d_2	− 930,800	d_2	0	d_2	0
		+ 5.2945		+0.22027		−0.22531		+1,046,500		+438,500		+562,250
		+ 0.8740		+0.17220		−0.18087		+ 36,784		+106,640		+156,690
		−65.429		+1.34057		−1.14818		+152,484		+545,140		+718,940
i_2		−341.11	g_2	+6.6316	h_2	+2.2162	k_2	+10,921,410	k_2	+ 467,902	k_2	+ 749,205
		+ 7.660		+1.0495		−1.0735		− 4,986,200		−2,089,300		−2,678,900
		− 4.005		+0.49115		−0.01862		− 946,570		− 198,670		− 259,790
		+ 0.010		−0.00923		+0.25831		− 418,860		+ 58,460		+ 101,930
				+0.00236		+0.00161		+ 281,880		+ 116,900		+ 46,887
		−337.44		+8.1654		+1.3840		+4,851,660		−1,644,708		−1,280,327
p_2		+233.81	n_2	+2.8259	o_2	+5.4122	q_2	+3,938,660	q_2	− 697,295	q_2	− 809,129
		+ 3.830		−0.71938		+0.73582		+3,418,000		+1,432,200		+1,836,300
		− 8.009		+0.24557		−0.009307		− 473,285		− 99,335		− 129,895
		+ 0.010		−0.018458		+0.51662		− 837,720		+ 116,920		+ 203,860
				+0.002360		+0.001614		+ 281,880		+ 116,900		+ 46,887
		+229.64		+2.3360		+6.6570		+6,327,535		+869,390		+1,148,023
A_2		+1.1065	B_2		C_2	+9.9940	D_2	+3,878,900	D_2	−1,315,000	D_2	−1,023,600
	−534.23	+4.7345				−4.1232		+ 628,750		+2,247,700		+2,964,300
	+452.39											
den.	− 81.84	+5.8410		+0.79950		+5.8708		+4,507,650		+932,700		+1,940,700
A_2'		+0.94540	B_2'		C_2'	−1.7753	D_2'	+898,600	D_2'	+123,460	D_2'	+163,040
	−152.85	−0.57230				+0.49840		− 76,000		−271,720		−358,330
	−307.88											
den.	−460.73	+0.37310		+0.14202		−1.2769		+822,600		−148,260		−195,290
α_2		−1.3640	β_2		γ_2		δ_2	+878,750	δ_2	−158,390	δ_2	−208,610
		−0.40062						−307,590		− 63,645		−132,430
		−1.7646		−0.054555		+0.15172		+571,160		−222,035		−341,040

$A_2 - A_2' = +5.4679$

For the Second Story.—*Continued.*

						For Wind on Face A Only.		For Floor and Ec. Col. Loads.		For Floor Loads Only.	
α_2'	+1.3071	β_2'	+0.14621	γ_2'	−0.025973	δ_2'	+673,950	δ_2'	+197,700	δ_2'	+390,650
α_2''	−0.015283 −0.036158 −0.022939 −0.074380	β_2''	−0.0011177 −0.0025659 −0.0036836	γ_2''	+0.0031091 +0.00045581 +0.0035649	δ_2''	+ 2,330.4 +11,703.0 −11,826.0 +2,207	δ_2''	+8,332.0 −4,549.8 −3,469.4 +312.8	δ_2''	+10,987 − 6,988.0 − 6,855.5 −2,856.5
α_2'''	+0.60630 −0.31834 −0.034946 +0.25301	β_2'''	+0.030026 −0.0098420 −0.0039091 +0.016275	γ_2'''	−0.029059 +0.027373 +0.00069438 −0.000992	δ_2'''	− 17,990 +103,030 − 18,017 − 47,411 +19,612	δ_2'''	− 2,549.6 −40,052 − 5,285.0 +56,151 +8,264	δ_2'''	+72,128 +23,283 −61,528 −10,444 +23,439
α_2^{iv}	−0.47066 +0.036284 +0.18952 −0.24486	β_2^{iv}	−0.023310 +0.0011217 +0.021200 −0.000988	γ_2^{iv}	+0.022558 −0.0031198 −0.0037660 +0.015672	δ_2^{iv}	+13,966 −11,743 +97,720 −74,230 +25,713	δ_2^{iv}	+ 1,979.4 + 4,565.3 +28,667 −42,968 −7,756.3	δ_2^{iv}	−56,459 −18,075 + 7,012.8 +56,647 −10,874
	$\alpha_2'''-\alpha_2^{iv}=+0.49787$		$\beta_2'''-\beta_2^{iv}=+0.017263$		$\gamma_2'''-\gamma_2^{iv}=-0.016664$		$\delta_2'''-\delta_2^{iv}=-6101$		$\delta_2'''-\delta_2^{iv}=+16,020$		$\delta_2'''-\delta_2^{iv}=+34,313$
α_2^{v}	+0.0025867 +0.13486 −0.096600 +0.04085	β_2^{v}	+0.00012810 +0.0041690 −0.010805 −0.006508	γ_2^{v}	−0.00012397 −0.011593 +0.0019194 −0.009798	δ_2^{v}	− 76.8 − 43,647 − 49,800 +1,374,358 +1,280,834	δ_2^{v}	− 10.9 + 16,969 − 14,610 +196,939 +199,287	δ_2^{v}	+57,213 + 99.3 +26,064 −28,870 +54,506
α_2^{vi}	+0.069807 −0.0050952 −0.0038610	β_2^{vi}	+0.0034571 −0.00015753 −0.00043185	γ_2^{vi}	−0.0033456 +0.00043812 +0.00007672	δ_2^{vi}	− 2,071.3 + 1,649.2 − 1,990.5 +13,719.0	δ_2^{vi}	− 293.6 − 641.2 − 584.0 +5,748.3	δ_2^{vi}	+7,370.6 +2,680.8 − 984.8 −1,153.9
$\alpha_2^{vi}-1=-0.939149$	+0.060851		+0.0028677		−0.0028308		+11,306		+4229.5		+7,912.7

For the Second Story.—*Continued.*

						For Wind on Face A Only.		For Floor and Ec. Col. Loads.		For Floor Loads Only.	
θ_2	−8.3510 +0.25301 −8.0980	ϕ_2	+0.14227 +0.025498 +0.016275 +0.18404	ψ_2	−0.025170 −0.000992 −0.026162	ω_2	−126,711 +100,540 + 19,612 −6,559	ω_2	0 +37,609 + 8,264 +45,873	ω_2	0 +23,439 +70,363 +93,802
θ_2'	+11.103 − 0.24486 +10.858	ϕ_2'	−0.033905 −0.000988 −0.034893	ψ_2'	+0.18917 +0.033469 +0.015672 +0.23831	ω_2'	−133,680 + 25,713 −107,967	ω_2'	−50,008 − 7,756.3 −57,764	ω_2'	−10,874 −93,555 −104,429
θ_2''	 +0.04085	ϕ_2''	−0.087260 −0.006508 −0.093768	ψ_2''	−0.087260 −0.009798 −0.097058	ω_2''	+ 260,810 +1,280,834 +1,541,644	ω_2''	+109,700 +199,287 +308,987	ω_2''	+97,442 +54,506 +151,948

For the Third Story.

c_3	−89.578 + 6.3480 + 0.9566 −82.273	a_3	+0.90705 +0.27353 +0.22011 +1.40069	b_3	−1.2060 −0.27000 −0.21247 −1.60885	d_3	− 583,400 +1,078,500 − 77,787 +417,313	d_3	0 +403,410 +204,250 +607,660	d_3	0 +754,730 +437,500 +1,192,230
i_3	−244.44 + 9.3610 − 4.5300 − 0.0113 −239.62	g_3	+6.2884 +0.74640 +0.60220 −0.018279 +0.001806 +7.6205	h_3	+3.5239 −0.73682 −0.03670 +0.289960 +0.002719 +3.04306	k_3	+6,804,722 −2,942,900 − 725,650 − 475,700 + 355,400 +3,015,872	k_3	+ 556,984 −1,100,900 − 305,770 + 143,500 + 55,300 −650,886	k_3	+ 806,207 −2,059,700 − 867,270 + 201,185 + 15,124 −1,904,454
p_3	+397.26 + 4.6805 − 9.060 − 0.011 +392.87	n_3	+2.6563 −1.2130 +0.30110 −0.03656 +0.001806 +1.7096	o_3	+8.0236 +1.1974 −0.018351 +0.579920 +0.002719 +9.78529	g_3	+2,416,672 +4,782,700 − 362,825 − 951,400 + 355,400 +6,240,547	g_3	− 608,213 +1,789,000 − 152,885 + 287,000 + 55,300 +1,370,202	g_3	− 752,127 +3,346,900 − 433,635 + 402,370 + 15,124 +2,578,632

For the Third Story.—*Continued.*

							For Wind on Face A Only.		For Floor and Ec. Col. Loads.		For Floor Loads Only.	
A_3	−626.97 +335.63	+0.85940 +1.38890	B_3		C_3	+3.5300 −0.82252	D_3	+851,700 +343,240	D_3	−183,800 +499,770	D_3	−537,750 +980,620
den.	−291.34	+2.2483		+0.28240		+2.7075		+1,194,940		+315,970		+442,870
A_3'	−140.65 −550.27	+1.1652 −0.96020	B_3'		C_3'	−1.4885 +0.56862	D_3'	+743,150 −237,290	D_3'	+163,180 −345,550	D_3'	+307,070 −677,980
den.	−690.92	+0.2050		+0.11908		−0.9199		+505,860		−182,370		−370,910
α_3		−1.0122 −0.27163	β_3		γ_3		δ_3	+556,600 −119,880	δ_3	−200,670 − 31,701	δ_3	−408,130 − 44,432
		−1.2838		−0.028333		+0.13103		+436,720		−232,371		−452,562
α_3'			β_3'		γ_3'		δ_3'		δ_3'		δ_3'	
		+1.7752		+0.13820		−0.05828		+337,230		+243,900		+398,250
α_3''		−0.012154 −0.021857 −0.036432	β_3''	−0.00048237 −0.0028362	γ_3''	+0.0022309 +0.0011960	δ_3''	+5,072.5 +7,435.5 −6,921.0	δ_3''	+7,385.8 −3,956.2 −5,005.7	δ_3''	+14,491 − 7,705.5 − 8,173.8
		−0.070443		−0.0033186		+0.0034269		+5,587.0		−1,576.1		−1,388
α_3'''		+0.57045 −0.23629 −0.046443	β_3'''	+0.026876 −0.0052145 −0.0036157	γ_3'''	−0.027752 +0.024118 +0.0015248	δ_3'''	−45,245 +80,382 − 8,823 − 6,559	δ_3'''	+12,764 −42,768 − 6,381.5 +45,873	δ_3'''	+93,802 +11,239 −83,295 −10,419
		+0.28772		+0.018046		−0.002109		+19,755		+9,488		+11,327
α_3^{iv}		−0.76497 +0.044798 +0.42310	β_3^{iv}	−0.036036 +0.0009887 +0.032937	γ_3^{iv}	+0.037210 −0.004572 −0.013890	δ_3^{iv}	+ 60,670 − 15,239 + 80,353 −107,967	δ_3^{iv}	−17,115 + 8,108.3 +58,125 −57,764	δ_3^{iv}	−104,429 − 15,071 + 15,792 + 94,910
		−0.29707		−0.002110		+0.018748		+17,817		−8,646		−8,798
		$\alpha_3'''-\alpha_3^{iv}=+0.58479$		$\beta_3'''-\beta_3^{iv}=+0.020156$		$\gamma_3'''-\gamma_3^{iv}=-0.020857$		$\delta_3'''-\delta_3^{iv}=+1938$		$\delta_3'''-\delta_3^{iv}=+18134$		$\delta_3'''-\delta_3^{iv}=+20125$

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For the Third Story.—*Continued.*

						For Wind on Face A Only.		For Floor and Ec. Col. Loads.		For Floor Loads Only.	
α_3^{v}	−0.0028778 +0.12038 −0.17231	β_3^{v}	−0.00013557 +0.0026568 −0.013413	γ_3^{v}	+0.00014000 −0.012288 +0.0056562	δ_3^{v}	+ 228.2 − 40,950 − 32,730 +1,541,644	δ_3^{v}	− 64.4 + 21,790 − 23,671 +308,987	δ_3^{v}	+151,948 − 56 + 42,438 − 38,653
	−0.05481		−0.010892		−0.006492		+1,468,192		+307,042		+155,677
α_3^{vi}	+0.066160 −0.0036817 −0.0050253	β_3^{vi}	+0.0031168 −0.00008125 −0.00039121	γ_3^{vi}	−0.0032184 +0.00037575 +0.00016498	δ_3^{vi}	− 5,247.0 + 1,252.4 − 954.6 +11,306	δ_3^{vi}	+1,480.1 − 666.4 − 690.4 +4,229.5	δ_3^{vi}	+7,912.7 +1,303.6 −1,297.9 −1,127.3
$\alpha_3^{vi}-1=-0.942547$	+0.057453		+0.0026443		−0.0026777		+6,356.8		+4,352.8		+6,791.1
θ_3	−17.278 + 0.28772	ϕ_3	+0.28200 +0.048473 +0.018046	ψ_3	−0.049083 −0.002109	ω_3	−123,726 +116,520 + 19,755	ω_3	0 +79,788 + 9,488	ω_3	0 + 11,327 +124,490
	−16.990		+0.34852		−0.051192		+12,549		+89,276		+135,817
θ_3'	+12.053 − 0.29707	ϕ_3'	−0.033816 −0.002110	ψ_3'	+0.19673 +0.034242 +0.018748	ω_3'	−81,295 +17,817	ω_3'	−55,662 − 8,646	ω_3'	− 8,798 −86,855
	+11.756		−0.035926		+0.24972		−63,478		−64,308		−95,653
θ_3''		ϕ_3''	−0.116240 −0.010892	ψ_3''	−0.116240 −0.006492	ω_3''	+ 109,850 +1,468,192	ω_3''	−245,620 +307,042	ω_3''	− 64,500 +155,677
	−0.05481		−0.127132		−0.122732		+1,578,042		+61,422		+91,177

For the Fourth Story.

c_4	−113.170 + 6.4527 + 0.85120	a_4	+1.5301 +0.31752 +0.22241	b_4	−1.0675 −0.32152 −0.23015	d_4	−477,450 +763,300 + 21,385	d_4	0 +522,630 +200,100	d_4	0 +815,500 +222,090
	−105.866		+2.0700		−1.6192		+307,235		+722,730		+1,037,590

For the Fourth Story.—*Continued.*

							For Wind on Face A Only.		For Floor and Ec. Col. Loads.		For Floor Loads Only.	
i_4		−375.61 + 5.9907 − 3.0926 + 0.0085 −372.70	g_4	+6.8894 +1.0537 +0.37572 −0.02196 +0.00170 +8.2986	h_4	+2.0662 −1.0670 −0.04391 +0.19516 +0.001014 +1.1515	k_4	+3,538,554 −2,533,300 − 411,300 − 185,470 + 229,250 +637,734	k_4	+ 493,937 −1,734,800 − 197,530 + 90,005 + 47,945 −1,300,443	k_4	+ 656,596 −2,706,600 − 235,820 = 91,585 + 24,310 −2,169,929
p_4		+212.50 + 2.9954 − 6.1852 + 0.0086 +209.32	n_4	+2.9538 −0.59618 +0.18786 −0.04393 +0.00170 +2.5032	o_4	+5.1142 +0.60370 −0.021955 +0.39032 +0.001014 +6.0873	g_4	+1,305,354 +1,433,300 − 205,650 − 370,940 + 229,250 +2,391,314	g_4	−705,022 +981,400 − 98,765 +180,010 + 47,945 +405,568	g_4	− 676,738 +1,531,200 − 117,910 + 183,170 + 24,310 +944,032
A_4	−878.65 +771.50	+1.1378 +5.6322	B_4		C_4	+9.8812 −3.4783	D_4	+ 630,150 +1,068,600	D_4	−1,285,100 +2,513,600	D_4	−2,144,000 +3,609,400
den.	−107.15	+6.7700		+0.98812		+6.4029		+1,698,750		+1,228,500		+1,465,400
A_4'	−265.03 −433.29	+0.92295 −0.48545 $A_4-A_4'=+6.3325$	B_4'		C_4'	−1.5162 +0.29980	D_4'	+362,580 − 92,105	D_4'	+ 61,497 −216,640	D_4'	+143,140 −311,090
den.	−698.32	+0.43750		+0.15162		−1.2164		+270,475		−155,143		−167,950
α_4		−1.3005 −0.44236 −1.7429	β_4	0	γ_4	0	δ_4	+289,150 −117,370 +171,780	δ_4	−165,870 − 84,885 −250,755	δ_4	−179,550 −101,240 −280,790
α_4'		+1.2032	β_4'	0	γ_4'	0	δ_4'	+257,940	δ_4'	+218,500	δ_4'	+225,550

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For the Fourth Story.—*Continued.*

						For Wind on Face A Only.		For Floor and Ec. Col. Loads.		For Floor Loads Only.	
α_4''	−0.0094450 −0.034078 −0.018401 −0.061924	β_4''	0	γ_4''	0	δ_4''	+2,901.9 +3,358.5 −3,449.5 +2,810.9	δ_4''	+6,826.0 −4,902.6 −3,341.5 −1,418.1	δ_4''	+9,800.5 −5,489.8 −3,944.9 +365.8
α_4^{vi}	+0.058368 −0.0046088 −0.0032220 +0.050537	β_4^{vi}	0	γ_4^{vi}	0	δ_4^{vi}	−2,649.5 + 454.2 − 604.0 +6,356.8 +3,557.5	δ_4^{vi}	+1,336.6 − 663.0 − 585.1 +4,352.8 +4,441.3	δ_4^{vi}	+6,791.1 − 344.8 − 742.5 − 690.7 +5,013.1

Referring now to the previous tables and Plates 14 and 16 all unknowns are found as follows (*for wind on face A, only*).

$H_4 = \delta_4^{vi} \div (1 - \alpha_4^{vi}) = + 3{,}557.5 \div 0.949463 = + 3{,}746.9$ lb.

$H_3 = - 0.061924\ H_4 + 2{,}810.9 = + 2{,}578.9$ lb.

$M_4^B = + 1.2032\ H_4 + 225{,}550 = + 230{,}058$ in. lb.

$M_4^A = - 1.7429\ H_4 + 171{,}780 = + 165{,}249$ in. lb.

$S_4^B = H_4 = + 3{,}746.9$ lb, $\quad S_4^A = F_4^A - H_4 = + 3{,}003.1$ lb.

$X_4^B = 230{,}058 \div 3{,}746.9 = + 61.403$ in.

$X_4^A = 165{,}249 \div 3{,}003.1 = + 55.025$ in.

$V_4^B = - 0.005\ M_4^A - 0.005\ M_4^B + 4{,}725 = + 2{,}748$ lb $= - V_4^A$.

$\lambda_4 = - 13.825\ S_4^A + 93{,}250 = + 51{,}790$ in.

$\Delta_4 = - 0.05481\ H_3 - 0.127132\ M_4^A - 0.122732\ M_4^B + 1{,}578{,}042$
$= + 1{,}528{,}655$ in.

$C_5^B = + 11.756\ H_3 - 0.035926\ M_4^A + 0.24972\ M_4^B - 63{,}478$
$= + 18{,}364.$

$C_5^A = - 16.990\ H_3 + 0.34852\ M_4^A - 0.051192\ M_4^B + 12{,}549$
$= + 14{,}548.$

$\Delta_3 = - 0.05481\ H_3 - 0.010892\ M_4^A - 0.006492\ M_4^B + 1{,}468{,}192$
$= + 1{,}464{,}757$ in.

$C_4^B = - 0.29707\ H_3 - 00.02110\ M_4^A + 0.018748\ M_4^B + 17{,}817$
$= + 21{,}015.5.$

$C_4^A = + 0.28772\ H_3 + 0.018046\ M_4^A - 0.002109\ M_4^B + 19{,}755$
$= + 22{,}994.$

$H_2 = - 0.070443\ H_3 - 0.0033186\ M_4^A + 0.0034269\ M_4^B + 5{,}587.0$
$= + 5{,}645.3$ lb.

$M_3^B = + 1.7752\ H_3 + 0.13820\ M_4^A - 0.05828\ M_4^B + 337{,}230$
$= + 351{,}238$ in. lb.

$M_3^A = - 1.2838\ H_3 - 0.028333\ M_4^A + 0.13103\ M_4^B + 436{,}720$
$= + 458{,}873$ in. lb.

$S_3^B = S_4^B + H_3 = + 6{,}325.8$ lb. $\quad S_3^A = 14{,}250 - S_3^B = + 7{,}924.2$ lb.

$X_3^B = 351{,}238 \div 6{,}325.8 = + 55.527$ in.

$X_3^A = 458{,}873 \div 7{,}924.2 = + 57.905$ in.

$V_3^B = - 0.005\ M_3^A - 0.005\ M_3^B + 14{,}944 = + 10{,}893$ lb $= - V_3^A$.

$\lambda_3 = +\ 11.760\ S_4^A - 11.760\ S_3^A + 88{,}250 = +\ 30{,}340$ in.

$\delta_4^B = +\ 12.788\ M_4^B + 5.540\ S_4^A + 130.0\ C_4^B - 3{,}740{,}000$
$= +\ 3{,}597{,}815$ in.

$\delta_4^A = +\ 18.330\ M_4^A - 795.0\ S_4^A + 130.0\ C_4^A = +\ 3{,}632{,}850$ in.

$\Delta_2 = +\ 0.04085\ H_2 - 0.006508\ M_3^A - 0.009798\ M_3^B + 1{,}280{,}834$
$= +\ 1{,}274{,}638$ in.

$C_3^B = -\ 0.24486\ H_2 - 0.000988\ M_3^A + 0.015672\ M_3^B + 25{,}713$
$= +\ 293{,}819.$

$C_3^A = +\ 0.25301\ H_2 + 0.016275\ M_3^A - 0.000992\ M_3^B + 19{,}612$
$= +\ 281{,}604.$

$H_1 = -\ 0.074380\ H_2 - 0.0036836\ M_3^A + 0.0035649\ M_3^B + 2{,}207$
$= +\ 13{,}489$ lb.

$M_2^B = +\ 1.3071\ H_2 + 0.14621\ M_3^A - 0.025973\ M_3^B + 673{,}950$
$= +\ 739{,}305$ in. lb.

$M_2^A = -\ 1.7646\ H_2 - 0.054555\ M_3^A + 0.15172\ M_3^B + 571{,}160$
$= +\ 589{,}454$ in. lb.

$S_2^B = S_3^B + H_2 = +\ 11971.1$ lb.

$S_2^A = 21{,}750 - S_2^B = +\ 9{,}778.9$ lb.

$X_2^B = 739{,}305 \div 11971.1 = +\ 61{,}759$ in.

$X_2^A = 589{,}454 \div 9{,}778.9 = +\ 60.283$ in.

$V_2^B = -\ 0.005\ M_2^A - 0.005\ M_2^B + 30{,}788 = +\ 24{,}144$ lb $= -\ V_2^A.$

$\lambda_2 = +\ 11.255\ S_3^A - 11.255\ S_2^A + 84{,}450 = +\ 63{,}542$ in.

$\delta_3^B = +\ 11.823\ M_3^B + 493.0\ S_3^A + 125.0\ C_3^B - 7{,}030{,}000$
$= +\ 4{,}709{,}240$ in.

$\delta_3^A = +\ 8.8920\ M_3^A - 371.0\ S_3^A + 125.0\ C_3^A = +\ 4{,}664{,}350$ in.

$\Delta_1 = -\ 0.034776\ H_1 - 0.0079794\ M_2^A - 0.0054566\ M_2^B$
$+\ 952{,}958 = +\ 944{,}174$ in.

$C_2^B = -\ 0.20306\ H_1 - 0.000468\ M_2^A + 0.013099\ M_2^B + 21{,}240$
$= +\ 30{,}374.4.$

$C_2^A = +\ 0.19421\ H_1 + 0.012452\ M_2^A - 0.000472\ M_2^B + 24{,}000$
$= +\ 31{,}253.5.$

$H_0 = -\ 0.077161\ H_1 - 0.0037643\ M_2^A + 0.0039665\ M_2^B + 3{,}245$
$= +\ 3{,}854.5$ lb.

$M_1^B = +\ 1.7552\ H_1 + 0.15671\ M_2^A - 0.056710\ M_2^B + 818{,}370$
$= +\ 871{,}192$ in. lb

$M_1^A = -1.14748\,H_1 - 0.017209\,M_2^A + 0.15211\,M_2^B + 929{,}910$
$= +1{,}030{,}674$ in. lb.

$S_1^B = S_2^B + H_1 = +13{,}320.0$ lb.

$S_1^A = 29{,}250 - S_1^B = +15{,}930.0$ lb.

$X_1^B = 871{,}192 \div 13{,}320.0 = +65.403$ in.

$X_1^A = 1{,}030{,}674 \div 15{,}930.0 = +64.705$ in.

$V_1^B = -0.005\,M_1^A - 0.005\,M_1^B + 52{,}256 = +42{,}747$ lb $= -V_1^A$.

$\lambda_1 = +9.845\,S_2^A - 9.845\,S_1^A + 73{,}800 = +13{,}269$ in.

$\delta_2^B = +6.9593\,M_2^B + 290.0\,S_2^A + 125.0\,C_2^B - 6{,}315{,}000$
$= +5{,}470{,}700$ in.

$\delta_2^A = +8.8920\,M_2^A - 371.0\,S_2^A + 125.0\,C_2^A = +5{,}525{,}490$ in.

$\Delta_0 = +0.0000158\,H_0 - 0.0051687\,M_1^A - 0.0051710\,M_1^B$
$+ 509{,}260 = +499{,}428$ in.

$C_1^B = -0.15661\,H_0 + 0.000374\,M_1^A + 0.010152\,M_1^B + 17{,}440$
$= +26{,}066.3.$

$C_1^A = +0.15657\,H_0 + 0.010150\,M_1^A + 0.000376\,M_1^B + 17{,}021$
$= +28{,}414.1.$

$S_0^B = +0.071624\,H_0 + 0.0034912\,M_1^A - 0.0034912\,M_1^B$
$+ 16{,}342.0 = +17{,}175.5$ lb.

$M_0^B = +2.5337\,H_0 + 0.22285\,M_1^A - 0.092265\,M_1^B + 1{,}237{,}800$
$= +1{,}396{,}896$ in. lb.

$M_0^A = -2.5341\,H_0 - 0.092290\,M_1^A + 0.22288\,M_1^B + 1{,}252{,}300$
$= +1{,}341{,}547$ in. lb.

$S_0^A = 33{,}000 - S_0^B = +15{,}825.5$ lb.

$X_0^B = 1{,}396{,}896 \div 17{,}175.5 = +81.333$ in.

$X_0^A = 1{,}341{,}547 \div 15{,}825.5 = +84.773$ in.

$V_0^B = -0.005\,M_0^A - 0.005\,M_0^B + 76{,}772 = +63{,}080$ lb. $= -V_0^A$.

$\lambda_0 = +8.450\,S_1^A - 8.450\,S_0^A + 31{,}670 = +32{,}567$ in.

$\delta_1^B = +6.9593\,M_1^B + 290.0\,S_1^A + 125.0\,C_1^B - 8{,}485{,}000$
$= +5{,}458{,}490$ in.

$\delta_1^A = +5.0374\,M_1^A - 210.0\,S_1^A + 125.0\,C_1^A = +5{,}400{,}460$ in.

$\delta_0^B = +5.0374\,M_0^B + 210.0\,S_0^A - 6{,}930{,}000 = +3{,}432{,}000$ in.

$\delta_0^A = +5.0374\,M_0^A - 210.0\,S_0^A = +3{,}436{,}700.$

Section.	x	By the Method of Chapter III.						By the Method of Chapter II.					
		V	S	M	$V \div A$	$Mv \div I$	Max. + Fibre.	V	S	M	$V \div A$	$Mv \div I$	Max + Fibre
A–0	125	−63,080	+15,825.5	− 636,641	−1,815	+3,337	+1,522	−66,475	+16,500	−1,031,000	−1,915	+5,400	+3,485
	0			+1,341,547	−1,815	+7,035	+5,220			+1,031,000	−1,915	+5,400	+3,485
B–0	125	+63,080	+17,175.5	− 749,916	+1,815	+3,930	+5,745	+66,475	+16,500	−1,031,000	+1,915	+5,400	+7,315
	0			+1,396,896	+1,815	+7,325	+9,140			+1,031,000	+1,915	+5,400	+7,315
A–1	125	−42,747	+15,930	− 960,576	−1,230	+5,035	+3,805	−43,112	+16,970	−1,120,000	−1,242	+5,870	+4,628
	0			+1,030,674	−1,230	+5,405	+4,175			+1,120,000	−1,242	+5,870	+4,628
B–1	125	+42,747	+13,320	− 793,808	+1,734	+5,740	+7,474	+43,112	+12,280	− 767,500	+1,748	+5,555	+7,303
	0			+ 871,192	+1,734	+6,300	+8,034			+ 767,500	+1,748	+5,555	+7,303
A–2	125	−24,144	+ 9,778.9	− 632,908	−1,225	+5,850	+4,625	−23,990	+ 9,553	− 597,500	−1,216	+5,525	+4,309
	0			+ 589,454	−1,225	+5,445	+4,220			+ 597,500	−1,216	+5,525	+4,309
B–2	125	+24,144	+11,971.1	− 757,083	+ 980	+5,475	+6,455	+23,990	+12,197	− 762,500	+ 974	+5,520	+6,494
	0			+ 739,305	+ 980	+5,345	+6,325			+ 762,500	+ 974	+5,520	+6,494
A–3	125	−10,893	+ 7,924.2	− 531,652	− 552	+4,915	+4,363	−10,480	+ 8,135	− 508,000	− 532	+4,700	+4,168
	0			+ 458,873	− 552	+4,225	+3,693			+ 508,000	− 532	+4,700	+4,168
B–3	125	+10,893	+ 6,325.8	− 439,487	+ 715	+5,405	+6,120	+10,480	+ 6,115	− 382,000	+ 688	+4,700	+5,388
	0			+ 351,238	+ 715	+4,320	+5,035			+ 382,000	+ 688	+4,700	+5,388
A–4	130	− 2,748	+ 3,003.1	− 225,154	− 239	+3,900	+3,661	− 2,532	+ 2,773	− 180,200	− 220	+3,125	+2,905
	0			+ 165,249	− 239	+2,865	+2,626			+ 180,200	− 220	+3,125	+2,905
B–4	130	+ 2,748	+ 3,746.9	− 257,039	+ 181	+3,160	+3,341	+ 2,532	+ 3,977	− 258,300	+ 166	+3,175	+3,341
	0			+ 230,058	+ 181	+2,830	+3,011			+ 258,300	+ 166	+3,175	+3,341

Checks.—

$H_4 + H_3 + H_2 + H_1 + H_0 = +17,174.5$ lb.

S_0^B, above, equals $+17,175.5$ lb; hence checks.

Fourth Story.

$$\left.\begin{array}{l} 12.5\ C_4^A + \delta_4^A + 10.0\ C_5^A - \lambda_4 = +4,013,965 \text{ in.} \\ 12.5\ C_4^B + \delta_4^B + 10.0\ C_5^B - \lambda_3 = +4,012,804 \text{ in.} \end{array}\right\} \text{Checks.}$$

Third Story.

$$\left.\begin{array}{l} 12.5\ C_3^A + \delta_3^A + 12.5\ C_4^A - \lambda_3 = +5,273,440 \text{ in.} \\ 12.5\ C_3^B + \delta_3^B + 12.5\ C_4^B - \lambda_2 = +5,275,661 \text{ in.} \end{array}\right\} \text{Checks.}$$

Second Story.

$$\left.\begin{array}{l} 12.5\ C_2^A + \delta_2^A + 12.5\ C_3^A - \lambda_2 = +6,204,622 \text{ in.} \\ 12.5\ C_2^B + \delta_2^B + 12.5\ C_3^B - \lambda_1 = +6,204,385 \text{ in.} \end{array}\right\} \text{Checks.}$$

First Story.

$$\left.\begin{array}{l} 12.5\ C_1^A + \delta_1^A + 12.5\ C_2^A - \lambda_1 = +6,133,036 \text{ in.} \\ 12.5\ C_1^B + \delta_1^B + 12.5\ C_2^B - \lambda_0 = +6,131,432 \text{ in.} \end{array}\right\} \text{Checks.}$$

O Story.

$$\left.\begin{array}{l} \delta_0^A + 12.5\ C_1^A - \lambda_0 = +3,759,309 \text{ in.} \\ \delta_0^B + 12.5\ C_1^B \qquad\quad = +3,757,829 \text{ in.} \end{array}\right\} \text{Checks.}$$

The accompanying table gives a comparison of Column Stresses by the methods of Chapters II and III.

The following table gives a comparison of the stresses in the top flanges of the girders at the left end ($x = 200$ in.).

Girder.	Chapter III.	Chapter II.
a–0	+84,497	+104,885
a–1	+75,530	+ 82,003
a–2	+55,345	+ 56,105
a–3	+34,629	+ 34,051
a–4	+14,633	+ 12,385

As will be noticed the comparisons for both column and girder stresses are very close, excepting in the basement or 0 story. A difference would naturally be expected here since, when the column is not vertical at the first floor the point of contraflexure in the 0 story column will be raised above mid height.

CHAPTER VII.

A STUDY OF THE EFFECT OF FLOOR AND ECCENTRIC COLUMN LOADS ON AN ELASTIC PORTAL BRACED BUILDING — WITH COMPARISONS.

Referring to the previous chapter, the stresses and deformations due to the combined floor and eccentric column loads will now be obtained and comparisons similar to those of that chapter will also be given here. Using the tables calculated in Chapter VI the following values are derived.

$H_4 \;= \delta_4^{\text{vi}} \div (1 - \alpha_4^{\text{vi}}) = +\,4441.3 \div 0.949463 = +\,4{,}677.8$ lb.

$H_3 \;= -\,0.061924\, H_4 - 1{,}418.1 = -\,1{,}707.8$ lb.

$M_4^B = +\,1.2032\, H_4 + 218{,}500 = +\,224{,}128$ in. lb.

$M_4^A = -\,1.7429\, H_4 - 250{,}755 = -\,258{,}909$ in. lb.

$S_4^B \;= H_4 = +\,4{,}677.8$ lb $= -\,S_4^A$.

$X_4^B = 224{,}128 \div 4{,}677.8 = +\,47.913$ in.,

$X_4^A = -\,258{,}909 \div -\,4{,}677.8 = +\,55.345$ in.

$V_4^B = -\,0.005\, M_4^A - 0.005\, M_4^B + 19{,}328 = +\,19{,}502$ lb.

$V_4^A = 52{,}500 - V_4^B = +\,32{,}998$ lb.

$\lambda_4 \;= -\,13.825\, S_4^A = +\,64{,}660$ in.

$\Delta_4 \;= -\,0.05481\, H_3 - 0.127132\, M_4^A - 0.122{,}732\, M_4^B + 61{,}422$
$= +\,66{,}922$ in.

$C_5^B \;= +\,11.756\, H_3 - 0.035926\, M_4^A + 0.24972\, M_4^B - 64{,}308$
$= -\,19{,}116.$

$C_5^A \;= -\,16.990\, H_3 + 0.34852\, M_4^A - 0.051192\, M_4^B + 89{,}276$
$= +\,16{,}581.$

$\Delta_3 \;= -\,0.05481\, H_3 - 0.010892\, M_4^A - 0.006492\, M_4^B + 307{,}042$
$= +\,308{,}501$ in.

$C_4^B \;= -\,0.29707\, H_3 - 0.002110\, M_4^A + 0.018748\, M_4^B - 8{,}646$
$= -\,3{,}390.5.$

$C_4^A \;= +\,0.28772\, H_3 + 0.018046\, M_4^A - 0.002109\, M_4^B + 9{,}488$
$= +\,3{,}851.6.$

$H_2 = -0.070443\,H_3 - 0.0033186\,M_4^A + 0.0034269\,M_4^B$
$- 1{,}576.1 = +170.8.$

$M_3^B = +1.7752\,H_3 + 0.13820\,M_4^A - 0.05828\,M_4^B + 243{,}900$
$= +192{,}021$ in. lb.

$M_3^A = -1.2838\,H_3 - 0.028333\,M_4^A + 0.13103\,M_4^B - 232{,}371$
$= -193{,}474$ in. lb.

$S_3^B = S_4^B + H_3 = +2{,}970.0$ lb $= -S_3^A.$

$X_3^B = 192{,}021 \div 2{,}970.0 = +64.655$ in.

$X_3^A = -193{,}474 \div -2{,}970.0 = +65.140$ in.

$V_3^B = -0.005\,M_3^A - 0.005\,M_3^B + 73{,}368 = +73{,}374$ lb.

$V_3^A = 153{,}975 - V_3^B = +80{,}601$ lb.

$\lambda_3 = +11.760\,S_4^A - 11.760\,S_3^A = -20{,}092$ in.

$\delta_4^B = +12.788\,M_4^B + 554.0\,S_4^A + 130.0\,C_4^B = -166{,}805$ in.

$\delta_4^A = +18.330\,M_4^A - 795.0\,S_4^A + 130.0\,C_4^A = -529{,}292$ in.

$\Delta_2 = +0.04085\,H_2 - 0.006508\,M_3^A - 0.009798 M_3^B + 199{,}287$
$= +198{,}672$ in.

$C_3^B = -0.24486\,H_2 - 0.000988\,M_3^A + 0.015672\,M_3^B - 7{,}756.3$
$= -4{,}597.3.$

$C_3^A = +0.25301\,H_2 + 0.016275\,M_3^A - 0.000992\,M_3^B + 8{,}264$
$= +4{,}967.8.$

$H_1 = -0.074380\,H_2 - 0.0036836\,M_3^A + 0.0035649\,M_3^B + 312.8$
$= +1{,}697.3$ lb.

$M_2^B = +1.3071\,H_2 + 0.14621\,M_3^A - 0.025973\,M_3^B + 197{,}7700$
$= +164{,}647$ in. lb.

$M_2^A = -1.7646\,H_2 - 0.054555\,M_3^A + 0.15172\,M_3^B - 222{,}035$
$= -182{,}648$ in. lb.

$S_2^B = S_3^B + H_2 = +3{,}140.8$ lb $= -S_2^A.$

$X_2^B = 164{,}647 \div 3{,}140.8 = +52.422$ in.,

$X_2^A = -182{,}648 \div -3{,}140.8 = +58.158$ in.

$V_2^B = -0.005\,M_2^A - 0.005\,M_2^B + 127{,}407 = +127{,}496$ lb.

$V_2^A = 255{,}450 - V_2^B = +127{,}954$ lb.

$\lambda_2 = +11.255\,S_3^A - 11.255\,S_2^A = +1{,}922$ in.

$\delta_3^B = +11.823\,M_3^B + 493.0\,S_3^A + 125.0\,C_3^B = +232{,}570$ in.

$\delta_3^A = +\ 8.8920\ M_3^A - 371.0\ S_3^A + 125.0\ C_3^A = +\ 1{,}020$ in.

$\Delta_1 = -\ 0.034776\ H_1 - 0.0079794\ M_2^A - 0.0054566\ M_2^B$
$+\ 395{,}169 = +\ 395{,}669$ in.

$C_2^B = -\ 0.20306\ H_1 - 0.000468\ M_2^A + 0.013099\ M_2^B - 2{,}964.5$
$= -\ 1{,}066.9.$

$C_2^A = +\ 0.19421\ H_1 + 0.012452\ M_2^A - 0.000472\ M_2^B + 5{,}037.6$
$= +\ 3{,}015.1.$

$H_0 = -\ 0.077161\ H_1 - 0.0037643\ M_2^A + 0.0039665\ M_2^B$
$-\ 1{,}631.7 = -\ 422.0$ lb.

$M_1^B = +\ 1.7552\ H_1 + 0.15671\ M_2^A - 0.056710\ M_2^B + 385{,}820$
$= +\ 350{,}837$ in. lb.

$M_1^A = -\ 1.14748\ H_1 - 0.017209\ M_2^A + 0.15211\ M_2^B - 363{,}821$
$= -\ 337{,}581$ in. lb.

$S_1^B = S_2^B + H_1 = +\ 4{,}838.1$ lb $= -\ S_1^A.$

$X_1^B = 350{,}837 \div 4{,}838.1 = +\ 72.517$ in.,

$X_1^A = -\ 337{,}581 \div -\ 4{,}838.1 = +\ 69.777$ in.

$V_1^B = -\ 0.005\ M_1^A - 0.005\ M_1^B + 181{,}446 = +\ 181{,}379$ lb.

$V_1^A = 356{,}925 - V_1^B = +\ 175{,}546$ lb.

$\lambda_1 = +\ 9.845\ S_2^A - 9.845\ S_1^A = +\ 16{,}696$ in.

$\delta_2^B = +\ 6.9593\ M_2^B + 290.0\ S_2^A + 125.0\ C_2^B = +\ 101{,}720$ in.

$\delta_2^A = +\ 8.8920\ M_2^A - 371.0\ S_2^A + 125.0\ C_2^A = -\ 83{,}700$ in.

$\Delta_0 = +\ 0.0000158\ H_0 - 0.0051687\ M_1^A - 0.0051710\ M_1^B$
$+\ 50{,}140 = +\ 50{,}071$ in.

$C_1^B = -\ 0.15661\ H_0 + 0.000374\ M_1^A + 0.010152\ M_1^B - 9{,}965$
$= -\ 6{,}463.3.$

$C_1^A = +\ 0.15657\ H_0 + 0.010150\ M_1^A + 0.000376\ M_1^B + 9{,}213$
$= +\ 5{,}852.3.$

$S_0^B = +\ 0.071624\ H_0 + 0.0034912\ M_1^A - 0.0034912\ M_1^B$
$+\ 6{,}850.6 = +\ 44{,}169$ lb $= -\ S_0^A.$

$M_0^B = +\ 2.5337\ H_0 + 0.22285\ M_1^A - 0.092265\ M_1^B + 304{,}530$
$= +\ 195{,}858$ in. lb.

$M_0^A = -\ 2.5341\ H_0 - 0.092290\ M_1^A + 0.22288\ M_1^B - 313{,}865$
$= -\ 203{,}443$ in. lb.

$X_0^B = 195{,}858 \div 4{,}416.9 = +\ 44.350$ in.

$X_0^A = -203{,}443 \div -4{,}416.9 = +46.068$ in.
$V_0^B = -0.005\ M_0^A - 0.005\ M_0^B + 247{,}446 = +247{,}482$ lb.
$V_0^A = 482{,}320 - V_0^B = +234{,}838$ lb.
$\lambda_0 = +8.450\ S_1^A - 8.450\ S_0^A = -3{,}565$ in.
$\delta_1^B = +6.9593\ M_1^B + 290.0\ S_1^A + 125.0\ C_1^B = +230{,}690$ in.
$\delta_1^A = +5.0374\ M_1^A - 210.0\ S_1^A + 125.0\ C_1^A = +46{,}390$ in.
$\delta_0^B = +5.0374\ M_0^B + 210.0\ S_0^A = +59{,}690$ in.
$\delta_0^A = +5.0374\ M_0^A - 210.0\ S_0^A = -97{,}910$ in.

Checks.

$H_4 + H_3 + H_2 + H_1 + H_0 = +4{,}416.1$ lb.
S_0^B, above, $= +4{,}416.9$; hence checks.

Fourth Story

$$\left.\begin{array}{l} 12.5\ C_4^A + \delta_4^A + 10.0\ C_5^A - \lambda_4 = -379{,}997 \text{ in.} \\ 12.5\ C_4^B + \delta_4^B + 10.0\ C_5^B - \lambda_3 = -380{,}254 \text{ in.} \end{array}\right\} \text{Checks.}$$

Third Story.

$$\left.\begin{array}{l} 12.5\ C_3^A + \delta_3^A + 12.5\ C_4^A - \lambda_3 = +131{,}354 \text{ in.} \\ 12.5\ C_3^B + \delta_3^B + 12.5\ C_4^B - \lambda_2 = +130{,}741 \text{ in.} \end{array}\right\} \text{Checks.}$$

Second Story.

$$\left.\begin{array}{l} 12.5\ C_2^A + \delta_2^A + 12.5\ C_3^A - \lambda_2 = +14{,}164 \text{ in.} \\ 12.5\ C_2^B + \delta_2^B + 12.5\ C_3^B - \lambda_1 = +14\ 222 \text{ in.} \end{array}\right\} \text{Checks.}$$

First Story.

$$\left.\begin{array}{l} 12.5\ C_1^A + \delta_1^A + 12.5\ C_2^A - \lambda_1 = +140{,}537 \text{ in.} \\ 12.5\ C_1^B + \delta_1^B + 12.5\ C_2^B - \lambda_0 = +140{,}128 \text{ in.} \end{array}\right\} \text{Checks.}$$

o Story.

$$\left.\begin{array}{l} \delta_0^A + 12.5\ C_1^A - \lambda_0 = -21{,}191 \text{ in.} \\ \delta_0^B + 12.5\ C_1^B \qquad\quad = -21{,}101 \text{ in.} \end{array}\right\} \text{Checks.}$$

The following table gives a comparison of column stresses by the methods of Chapters II and III.

Section.	X	By the Method of Chapter III.						By the Method of Chapter II.					
		V	S	M	$V \div A$	$Mv \div I$	Max. + Fibre.	V	S	M	$V \div A$	$Mv \div I$	Max. + Fibre.
A–0	125	+234,838	−4,416.9	+348,669	+6,770	+1,828	+8,598	+234,874	0	0	+6,770	0	+6,770
	0			−203,443	+6,770	+1,066	+7,836					0	+6,770
B–0	125	+247,482	+4,416.9	−356,254	+7,130	+1,868	+8,998	+247,446	0	0	+7,130	0	+7,130
	0			+195,858	+7,130	+1,026	+8,156					0	+7,130
A–1	125	+175,546	−4,838.1	+267,181	+5,057	+1,401	+6,458	+175,479	0	0	+5,055	0	+5,055
	0			−337,581	+5,057	+1,769	+6,826					0	+5,055
B–1	125	+181,379	+4,838.1	−253,925	+7,365	+1,837	+9,202	+181,446	0	0	+7,368	0	+7,368
	0			+350,837	+7,365	+2,540	+9,905					0	+7,368
A–2	125	+127,954	−3,140.8	+209,952	+6,485	+1,942	+8,427	+128,043	0	0	+6,489	0	+6,489
	0			−182,648	+6,485	+1,690	+8,175					0	+6,489
B–2	125	+127,496	+3,140.8	−227,953	+5,175	+1,650	+6,825	+127,407	0	0	+5,171	0	+5,171
	0			+164,647	+5,175	+1,191	+6,366					0	+5,171
A–3	125	+ 80,601	−2,970.0	+177,776	+4,080	+1,644	+5,724	+ 80,607	0	0	+4,080	0	+4,080
	0			−193,474	+4,080	+1,789	+5,869					0	+4,080
B–3	125	+ 73,374	+2,970.0	−179,229	+4,820	+2,203	+7,023	+ 73,368	0	0	+4,820	0	+4,820
	0			+192,021	+4,820	+2,360	+7,180					0	+4,820
A–4	130	+ 32,998	−4,677.8	+349,205	+2,864	+6,055	+8,919	+ 33,172	0	0	+2,878	0	+2,878
	0			−258,909	+2,864	+4,485	+7,349					0	+2,878
B–4	130	+ 19,502	+4,677.8	−383,986	+1,281	+4,720	+6,001	+ 19,328	0	0	+1,270	0	+1,270
	0			+224,128	+1,281	+2,759	+4,040					0	+1,270

The following table gives a comparison of the stresses in the top flanges of the girders at mid span (x = 100 in.) and at the left end (x = 200 in.).

Girder.	Chapter III.		Chapter II.	
	$X = 200$	$X = 100$	$X = 200$	$X = 100$
a–0	−42,387	+30,111	−10,100	+62,750
a–1	−31,234	+18,384	−10,100	+38,830
a–2	−29,207	+19,455	−10,100	+38,830
a–3	−32,245	+17,417	−10,100	+38,830
a–4	−23,000	+29,490	− 6,710	+46,610

Attention is called to the large bending moments in the columns, causing stresses not taken care of in the design.

CHAPTER VIII.

A STUDY OF THE EFFECT OF UNIFORM FLOOR LOADS ALONE ON AN ELASTIC PORTAL BRACED BUILDING — WITH COMPARISONS.

As in the previous chapter these calculations refer back to the tables of Chapter VI. The values for this loading become:

$H_4 \;= \delta_4^{\text{vi}} \div (1 - \alpha_4^{\text{vi}}) = +\,5{,}013.1 \div 0.949463 = +\,5{,}280.0$ lb.

$H_3 \;= -\,0.061924\,H_4 + 365.8 = +\,38.8$ lb.

$M_4^B = +\,1.2032\,H_4 + 257{,}940 = +\,264{,}294$ in. lb.

$M_4^A = -\,1.7429\,H_4 - 280{,}790 = -\,289{,}993$ in. lb.

$S_4^B \;= H_4 = +\,5{,}280.0$ lb $= -\,S_4^A$.

$X_4^B = 264{,}294 \div 5{,}280.0 = +\,50.052$ in.,

$X_4^A = -\,289{,}993 \div -\,5{,}280.0 = +\,54.920$ in.

$V_4^B = -\,0.005\,M_4^A - 0.005\,M_4^B + 20{,}000 = +\,20{,}128$ lb.

$V_4^A = 40{,}000 - V_4^B = +\,19{,}872$ lb.

$\lambda_4 \;= -\,13.825\,S_4^A = +\,72{,}980$ in.

$\Delta_4 \;= -\,0.05481\,H_3 - 0.127132\,M_4^A - 0.122732\,M_4^B + 91{,}177$
$= +\,95{,}607$ in.

$C_5^B = +\,11.756\,H_3 - 0.035926\,M_4^A + 0.24972\,M_4^B - 95{,}653$
$= -\,18{,}780.$

$C_5^A = -\,16.990\,H_3 + 0.34852\,M_4^A - 0.051192\,M_4^B + 135{,}817$
$= +\,20{,}564.$

$\Delta_3 \;= -\,0.05481\,H_3 - 0.010892\,M_4^A - 0.006492\,M_4^B + 155{,}677$
$= +\,157{,}118$ in.

$C_4^B = -\,0.29707\,H_3 - 0.002110\,M_4^A + 0.018748\,M_4^B - 8{,}798$
$= -\,3{,}242.8.$

$C_4^A = +\,0.28772\,H_3 + 0.018046\,M_4^A - 0.002109\,M_4^B + 11{,}327$
$= +\,5{,}548.$

$H_2 \;= -\,0.070443\,H_3 - 0.0033186\,M_4^A + 0.0034269\,M_4^B - 1{,}388$
$= +\,477.3$ lb.

$$M_3^B = +1.7752\,H_3 + 0.13820\,M_4^A - 0.05828\,M_4^B + 398{,}250$$
$$= +342{,}840 \text{ in. lb.}$$
$$M_3^A = -1.2838\,H_3 - 0.028333\,M_4^A + 0.13103\,M_4^B - 452{,}562$$
$$= -409{,}765 \text{ in. lb.}$$
$$S_3^B = S_4^B + H_3 = +5{,}318.8 \text{ lb} = -S_3^A.$$
$$X_3^B = 342{,}840 \div 5{,}318.8 = +64.458 \text{ in.}$$
$$X_3^A = -409{,}765 \div -5{,}318.8 = +77.038 \text{ in.}$$
$$V_3^B = -0.005\,M_3^A - 0.005\,M_3^B + 43{,}375 = +43{,}710 \text{ lb.}$$
$$V_3^A = 86{,}750 - V_3^B = +43{,}040 \text{ lb.}$$
$$\lambda_3 = +11.760\,S_4^A - 11.760\,S_3^A = +457 \text{ in.}$$
$$\delta_4^B = +12.788\,M_4^B + 554.0\,S_4^A + 130.0\,C_4^B = +32{,}086 \text{ in.}$$
$$\delta_4^A = +18.330\,M_4^A - 795.0\,S_4^A + 130.0\,C_4^A = -400{,}260 \text{ in.}$$
$$\Delta_2 = +0.04085\,H_2 - 0.006508\,M_3^A - 0.009798\,M_3^B + 54{,}506$$
$$= +53{,}834 \text{ in.}$$
$$C_3^B = -0.24486\,H_2 - 0.000988\,M_3^A + 0.015672\,M_3^B - 10{,}874$$
$$= -5{,}212.5.$$
$$C_3^A = +0.25301\,H_2 + 0.016275\,M_3^A - 0.000992\,M_3^B + 23{,}439$$
$$= +16{,}550.2.$$
$$H_1 = -0.074380\,H_2 - 0.0036836\,M_3^A + 0.0035649\,M_3^B - 2{,}856.5$$
$$= -160.3 \text{ lb.}$$
$$M_2^B = +1.3071\,H_2 + 0.14621\,M_3^A - 0.025973\,M_3^B + 390{,}650$$
$$= +322{,}451 \text{ in. lb.}$$
$$M_2^A = -1.7646\,H_2 - 0.054555\,M_3^A + 0.15172\,M_3^B - 341{,}040$$
$$= -267{,}511 \text{ in. lb.}$$
$$S_2^B = S_3^B + H_2 = +5{,}796.1 = -S_2^A.$$
$$X_2^B = 322{,}451 \div 57{,}96.1 = +55.635 \text{ in.}$$
$$X_2^A = -267{,}511 \div -5{,}796.1 = +46.159 \text{ in.}$$
$$V_2^B = -0.005\,M_2^A - 0.005\,M_2^B + 66{,}750 = +66{,}475 \text{ lb.}$$
$$V_2^A = 133{,}500 - V_2^B = +67{,}025 \text{ lb.}$$
$$\lambda_2 = +11.255\,S_3^A - 11.255\,S_2^A = +5{,}372 \text{ in.}$$
$$\delta_3^B = +11.823\,M_3^B + 493.0\,S_3^A + 125.0\,C_3^B = +781{,}740 \text{ in.}$$
$$\delta_3^A = +8.8920\,M_3^A - 371.0\,S_3^A + 125.0\,C_3^A = +395{,}770 \text{ in.}$$
$$\Delta_1 = -0.034776\,H_1 - 0.0079794\,M_2^A - 0.0054566\,M_2^B + 158{,}513$$
$$= +158{,}894 \text{ in.}$$

$C_2^B = -0.20306\ H_1 - 0.000468\ M_2^A + 0.013099\ M_2^B - 5{,}169$
$= -787.3.$

$C_2^A = +0.19421\ H_1 + 0.012452\ M_2^A - 0.000472\ M_2^B + 6{,}587$
$= +3{,}072.4.$

$H_0 = -0.077161\ H_1 - 0.0037643\ M_2^A + 0.0039665\ M_2^B - 2{,}591$
$= -292.5$ lb.

$M_1^B = +1.7552\ H_1 + 0.15671\ M_2^A - 0.056710\ M_2^B + 472{,}400$
$= +411{,}907$ in. lb.

$M_1^A = -1.14748\ H_1 - 0.017209\ M_2^A + 0.15211\ M_2^B - 460{,}759$
$= -406{,}918$ in. lb.

$S_1^B = S_2^B + H_1 = +5{,}635.8$ lb $= -S_1^A$.

$X_1^B = 411{,}907 \div 5{,}635.8 = +73.088$ in.

$X_1^A = -406{,}918 \div -5{,}635.8 = +72.204$ in.

$V_1^B = -0.005\ M_1^A - 0.005\ M_1^B + 90{,}125 = +90{,}100$ lb.

$V_1^A = 180{,}250 - V_1^B = +90{,}150$ lb.

$\lambda_1 = +9.845\ S_2^A - 9.845\ S_1^A = -1{,}577$ in.

$\delta_2^B = +6.9593\ M_2^B + 290.0\ S_2^A + 125.0\ C_2^B = +464{,}990$ in.

$\delta_2^A = +8.8920\ M_2^A - 371.0\ S_2^A + 125.0\ C_2^A = +152{,}550$ in.

$\Delta_0 = +0.0000158\ H_0 - 0.0051687\ M_1^A - 0.0051710\ M_1^B + 2$
$= -5$ in.

$C_1^B = -0.15661\ H_0 + 0.000374\ M_1^A + 0.010152\ M_1^B - 11{,}512$
$= -7{,}436.4$

$C_1^A = +0.15657\ H_0 + 0.010150\ M_1^A + 0.000376\ M_1^B + 11{,}508$
$= +7{,}486.9.$

$S_0^B = +0.071624\ H_0 + 0.0034912\ M_1^A - 0.0034912$
$M_1^B + 8{,}223.2 = +5{,}343.5$ lb $= -S_0^A$.

$M_0^B = +2.5337\ H_0 + 0.22285\ M_1^A - 0.092265\ M_1^B + 371{,}110$
$= +241{,}671$ in. lb.

$M_0^A = -2.5341\ H_0 - 0.092290\ M_1^A + 0.22288\ M_1^B - 371{,}170$
$= -241{,}063$ in. lb.

$X_0^B = 241{,}671 \div 5{,}343.5 = +45.228$ in.

$X_0^A = -241{,}063 \div -5{,}343.5 = +45.115$ in.

$V_0^B = -0.005\ M_0^A - 0.005\ M_0^B + 125{,}460 = +125{,}457$ lb.

$V_0^A = 250{,}920 - V_0^B = +125{,}463$ lb.

$\lambda_0 \quad = +\,8.450\ S_1^A - 8.450\ S_0^A = -\,2{,}471.$

$\delta_1^B \quad = +\,6.9593\ M_1^B + 290.0\ S_1^A + 125.0\ C_1^B = +\,30{,}2850$ in.

$\delta_1^A \quad = +\,5.0374\ M_1^A - 210.0\ S_1^A + 125.0\ C_1^A = +\,68{,}860$ in.

$\delta_0^B \quad = +\,5.0374\ M_0^B + 210.0\ S_0^A = +\,95{,}863$ in.

$\delta_0^A \quad = +\,5.0374\ M_0^A - 210.0\ S_0^A = -\,92{,}810$ in.

Checks.

$H_4 + H_3 + H_2 + H_1 + H_0 = +\,5{,}343.3$ lb.

S_0^B, above, equals $+\,5{,}343.5$ lb; hence checks.

Fourth Story.

$$\left.\begin{array}{l} 12.5\ C_4^A + \delta_4^A + 10.0\ C_5^A - \lambda_4 = -\,197{,}336 \text{ in.} \\ 12.5\ C_4^B + \delta_4^B + 10.0\ C_5^B - \lambda_3 = -\,196{,}706 \text{ in.} \end{array}\right\}\text{ Checks.}$$

Third Story

$$\left.\begin{array}{l} 12.5\ C_3^A + \delta_3^A + 12.5\ C_4^A - \lambda_3 = +\,671{,}540 \text{ in.} \\ 12.5\ C_3^B + \delta_3^B + 12.5\ C_4^B - \lambda_2 = +\,670{,}677 \text{ in.} \end{array}\right\}\text{ Checks.}$$

Second Story

$$\left.\begin{array}{l} 12.5\ C_2^A + \delta_2^A + 12.5\ C_3^A - \lambda_2 = +\,392{,}460 \text{ in.} \\ 12.5\ C_2^B + \delta_2^B + 12.5\ C_3^B - \lambda_1 = +\,391{,}570 \text{ in.} \end{array}\right\}\text{ Checks.}$$

First Story.

$$\left.\begin{array}{l} 12.5\ C_1^A + \delta_1^A + 12.5\ C_2^A - \lambda_1 = +\,202{,}428 \text{ in.} \\ 12.5\ C_1^B + \delta_1^B + 12.5\ C_2^B + \lambda_0 = +\,202{,}525 \text{ in.} \end{array}\right\}\text{ Checks.}$$

o Story.

$$\left.\begin{array}{l} \delta_0^A + 12.5\ C_1^A - \lambda_0 = +\,3{,}247 \text{ in.} \\ \delta_0^B + 12.5\ C_1^B \qquad\ = +\,2{,}908 \text{ in.} \end{array}\right\}\text{ Checks.}$$

The following table gives a comparison of Column Stresses by the methods of Chapters II and III.

Section.	X	By the Method of Chapter III. V	S	M	$V \div A$	$Mv \div I$	Max. + Fibre.	By the Method of Chapter II. V	S	M	$V \div A$	$Mv \div I$	Max. + Fibre.
A–0	125	+125,463	−5,343.5	+426,875	+3,612	+2,237	+5,849	+125,460	0	0	+3,612	0	+3,612
	0			−241,063	+3,612	+1,263	+4,875				+3,612	0	+3,612
B–0	125	+125,457	+5,343.5	−426,267	+3,612	+2,235	+5,847	+125,460	0	0	+3,612	0	+3,612
	0			+241,671	+3,612	+1,267	+4,879				+3,612	0	+3,612
A–1	125	+ 90,150	−5,635.8	+297,557	+2,596	+1,559	+4,155	+ 90,125	0	0	+2,596	0	+2,596
	0			−406,918	+2,596	+2,130	+4,726				+2,596	0	+2,596
B–1	125	+ 90,100	+5,635.8	−292,568	+3,657	+2,117	+5,774	+ 90,125	0	0	+3,658	0	+3,658
	0			+411,907	+3,657	+2,980	+6,637				+3,658	0	+3,658
A–2	125	+ 67,025	−5,796.1	+457,001	+3,398	+4,225	+7,623	+ 66,750	0	0	+3,384	0	+3,384
	0			−267,511	+3,398	+2,474	+5,872				+3,384	0	+3,384
B–2	125	+ 66,475	+5,796.1	−402,061	+2,697	+2,908	+5,605	+ 66,750	0	0	+2,708	0	+2,708
	0			+322,451	+2,697	+2,333	+5,030				+2,708	0	+2,708
A–3	125	+ 43,040	−5,318.8	+255,085	+2,182	+2,357	+4,539	+ 43,375	0	0	+2,198	0	+2,198
	0			−409,765	+2,182	+3,790	+5,972				+2,198	0	+2,198
B–3	125	+ 43,710	+5,318.8	−322,010	+2,868	+3,960	+6,828	+ 43,375	0	0	+2,850	0	+2,850
	0			+342,840	+2,868	+4,220	+7,088				+2,850	0	+2,850
A–4	130	+ 19,872	−5,280.0	+370,007	+1,725	+6,415	+8,140	+ 20,000	0	0	+1,736	0	+1,736
	0			−289,993	+1,725	+5,025	+6,750				+1,736	0	+1,736
B–4	130	+ 20,128	+5,280.0	−395,706	+1,322	+4,865	+6,187	+ 20,000	0	0	+1,314	0	+1,314
	0			+264,294	+1,322	+3,253	+4,575				+1,314	0	+1,314

The following table gives a comparison of the stresses in the top flanges of the girders at mid span ($x = 100$ in.) and at the left end ($x = 200$ in.). Attention is called to the large bending moments in the columns causing stresses not taken care of in the design.

Girder.	Chapter III.		Chapter II.	
	$X = 200$.	$X = 100$.	$X = 200$.	$X = 100$.
a–0	−38,987	+31,595	0	+70,670
a–1	−28,399	+17,351	0	+46,750
a–2	−39,990	+ 9,200	0	+46,750
a–3	−27,083	+18,839	0	+46,750
a–4	−18,500	+30,860	0	+50,000

CHAPTER IX.

A STUDY OF THE EFFECT OF ECCENTRIC COLUMN LOADING ON AN ELASTIC PORTAL BRACED BUILDING — WITH COMPARISONS.

Since Chapter VII gives all values for these eccentric column loads and the floor loads combined, and Chapter VIII gives all values for the floor loads alone, it is evident that most values for this chapter may be found by subtracting the values of Chapter VIII from those of Chapter VII. The only exception will be the values of the points of contraflexure coordinates. These values are then as follows:

$H_4 = +4{,}677.8 - 5{,}280.0 = -602.2$ lb.

$H_3 = -1{,}707.8 - 38.8 = -1{,}746.6$ lb.

$M_4^B = +224{,}128 - 264{,}294 = -40{,}166$ in. lb.

$M_4^A = -258{,}909 + 289{,}993 = +31{,}084$ in. lb.

$S_4^B = H_4 = -602.2$ lb $= -S_4^A$.

$X_4^B = -40{,}166 \div -602.2 = +66.68$ in.

$X_4^A = 31{,}084 \div 602.2 = +51.60$ in.

$V_4^B = +19{,}502 - 20{,}128 = -626$ lb.

$V_4^A = +32{,}998 - 19{,}872 = +13{,}126$ lb.

$\lambda_4 = +64{,}660 - 72{,}980 = -8{,}320$ in.

$\Delta_4 = +66{,}922 - 95{,}607 = -28{,}685$ in.

$C_5^B = -19{,}116 + 18{,}780 = -336$.

$C_5^A = +16{,}581 - 20{,}564 = -3{,}983$.

$\Delta_3 = +308{,}501 - 157{,}118 = +151{,}383$ in.

$C_4^B = -3{,}390.5 + 3{,}242.8 = -147.7$.

$C_4^A = +3{,}851.6 - 5{,}548 = -1{,}696.4$.

$H_2 = +170.8 - 477.3 = -306.5$ lb.

$M_3^B = +192{,}021 - 342{,}840 = -150{,}819$ in. lb.

$M_3^A = -193{,}474 + 409{,}765 = +216{,}291$ in. lb.

$S_3^B = S_4^B + H_3 = -2{,}348.8$ lb $= -S_3^A$.

$X_3^B = -150,819 \div -2,348.8 = +64.20$ in.
$X_3^A = 216,291 \div 2,348.8 = +92.10$ in.
$V_3^B = +73,374 - 43,710 = +29,664$ lb.
$V_3^A = +80,601 - 43,040 = +37,561$ lb.
$\lambda_3 = -20,092 - 457 = -20,549$ in.
$\delta_4^B = -166,805 - 32,086 = -198,891$ in.
$\delta_4^A = -529,292 + 400,260 = -129,032$ in.
$\Delta_2 = +198,672 - 53,834 = +144,838$ in.
$C_3^B = -4,597.3 + 5,212.5 = +615.2.$
$C_3^A = +4,967.8 - 16,550.2 = -11,582.4.$
$H_1 = +1,697.3 + 160.3 = +1,857.6$ lb.
$M_2^B = +164,647 - 322,451 = -157,804$ in. lb.
$M_2^A = -182,648 + 267,511 = +84,863$ in. lb.
$S_2^B = S_3^B + H_2 = -2,655.3$ lb $= -S_2^A.$
$X_2^B = -157,804 \div -2,655.3 = +59.43$ in.
$X_2^A = 84,863 \div 2,655.3 = +31.98$ in.
$V_2^B = +127,496 - 66,475 = +61,021$ lb.
$V_2^A = +127,954 - 67,025 = +60,929$ lb.
$\lambda_2 = +1,922 - 5,372 = -3,450$ in.
$\delta_3^B = +232,570 - 781,740 = -549,170$ in.
$\delta_3^A = +1,020 - 395,770 = -394,750$ in.
$\Delta_1 = +395,669 - 158,894 = +236,775$ in.
$C_2^B = -1,066.9 + 787.3 = -279.6.$
$C_2^A = +3,015.1 - 3,072.4 = -57.3.$
$H_0 = -422.0 + 292.5 = -129.5$ lb.
$M_1^B = +350,837 - 411,907 = -61,070$ in. lb.
$M_1^A = -337,581 + 406,918 = +69,337$ in. lb.
$S_1^B = S_2^B + H_1 = -797.7$ lb $= -S_1^A.$
$X_1^B = -61,070 \div -797.7 = +76.60$ in.
$X_1^A = 69,337 \div 797.7 = +86.93$ in.
$V_1^B = +181,379 - 90,100 = +91,279$ lb.
$V_1^A = +175,546 - 90,150 = +85,396$ lb.

$\lambda_1 \;= + 16{,}696 + 1{,}577 = + 18{,}273$ in.

$\delta_2^B \;= + 101{,}720 - 464{,}990 = - 363{,}270$ in.

$\delta_2^A \;= - 83{,}700 - 152{,}550 = - 236{,}250$ in.

$\Delta_0 \;= + 50{,}071 + 5 = + 50{,}076$ in.

$C_1^B \;= - 6{,}463.3 + 7{,}436.4 = + 973.1.$

$C_1^A \;= + 5{,}852.3 - 7{,}486.9 = - 1{,}634.6.$

$S_0^B \;= + 4{,}416.9 - 5{,}343.5 = - 926.6$ lb $= - S_0^A.$

$M_0^B = + 195{,}858 - 241{,}671 = - 45{,}813$ in. lb.

$M_0^A = - 203{,}443 + 241{,}063 = + 37{,}620$ in. lb.

$X_0^B \;= - 45{,}813 \div - 926.6 = + 49.46$ in.

$X_0^A \;= 37{,}620 \div 926.6 = + 40.60$ in.

$V_0^B \;= + 247{,}482 - 125{,}457 = + 122{,}025$ lb.

$V_0^A \;= + 234{,}838 - 125{,}463 = + 109{,}375$ lb.

$\lambda_0 \;= - 3{,}565 + 2{,}471 = - 1{,}094$ in.

$\delta_1^B \;= + 230{,}690 - 302{,}850 = - 72{,}160$ in.

$\delta_1^A \;= + 46{,}390 - 68{,}860 = - 22{,}470$ in.

$\delta_0^B \;= + 59{,}690 - 95{,}863 = - 36{,}173$ in.

$\delta_0^A \;= - 97{,}910 + 92{,}810 = - 5{,}100$ in.

Checks.

Since Chapter VII and VIII checked, this chapter will also check if no errors have been made in the subtractions. The checks are all satisfied but are not given here.

The following table gives a comparison of column stresses by the methods of Chapters II and III.

Section.	X	By the Method of Chapter III.						By the Method of Chapter II.					
		V	S	M	$V \div A$	$Mv \div I$	Max. + Fibre.	V	S	M	$V \div A$	$Mv \div I$	Max. + Fibre.
A–0	125	+109,375	+ 926.6	− 78,205	+3,152	+ 409	+3,561	+109,414	0	0	+3,152	0	+3,152
	0			+ 37,620	+3,152	+ 197	+3,349				+3,152	0	+3,152
B–0	125	+122,025	− 926.6	+ 70,012	+3,512	+ 367	+3,879	+121,986	0	0	+3,512	0	+3,512
	0			− 45,813	+3,512	+ 240	+3,752				+3,512	0	+3,512
A–1	125	+ 85,396	+ 797.7	− 30,375	+2,459	+ 159	+2,618	+ 85,354	0	0	+2,459	0	+2,459
	0			+ 69,337	+2,459	+ 364	+2,823				+2,459	0	+2,459
B–1	125	+ 91,279	− 797.7	+ 38,642	+3,702	+ 280	+3,982	+ 91,321	0	0	+3,704	0	+3,704
	0			− 61,070	+3,702	+ 442	+4,144				+3,704	0	+3,704
A–2	125	+ 60,929	+2,655.3	−247,049	+3,086	+2,283	+5,369	+ 61,293	0	0	+3,106	0	+3,106
	0			+ 84,863	+3,086	+ 785	+3,871				+3,106	0	+3,106
B–2	125	+ 61,021	−2,655.3	+174,108	+2,477	+1,261	+3,738	+ 60,657	0	0	+2,461	0	+2,461
	0			−157,804	+2,477	+1,142	+3,619				+2,461	0	+2,461
A–3	125	+ 37,561	+2,348.8	− 77,309	+1,902	+ 715	+2,617	+ 37,232	0	0	+1,887	0	+1,887
	0			+216,291	+1,902	+2,001	+3,903				+1,887	0	+1,887
B–3	125	+ 29,664	−2,348.8	+142,781	+1,948	+1,756	+3,704	+ 29,993	0	0	+1,971	0	+1,971
	0			−150,819	+1,948	+1,855	+3,803				+1,971	0	+1,971
A–4	130	+ 13,126	+ 602.2	− 44,191	+1,139	+ 766	+1,905	+ 13,172	0	0	+1,143	0	+1,143
	0			+ 31,084	+1,139	+ 539	+1,678				+1,143	0	+1,143
B–4	130	− 626	− 602.2	+ 35,109	− 41	+ 432	+ 391	− 672	0	0	− 44	0	− 44
	0			− 40,166	− 41	+ 494	+ 453				− 44	0	− 44

The following table gives a comparison of the stresses in the top flanges of the girders at mid span ($x = 100$ in.) and at the left end ($x = 200$ in.).

Girder.	Chapter III.		Chapter II.	
	$X = 200$ in.	$X = 100$ in.	$X = 200$ in.	$X = 100$ in.
a–0	− 3,400	− 1,484	−10,100	−7,920
a–1	− 2,835	+ 1,033	−10,100	−7,920
a–2	+10,783	+10,255	−10,100	−7,920
a–3	− 5,162	− 1,422	−10,100	−7,920
a–4	− 4,500	− 1,370	− 6,710	−3,390

Note that the bending moments from eccentric loads do not follow the rules deduced by Professor Heller.

COMPARISON SUMMARY—CHAPTERS VI, VII, VIII, AND IX.

In the following table, computed from those of Chapters VI, VIII, and IX, the simultaneous compressive unit fibre stresses are given for wind on face A, floor, and eccentric column loadings; in each case the figures are given for the fibre which receives the maximum total combined unit stress, the object of the table being to deduce and compare the maximum possible stresses in the columns. The table gives this comparison for the methods of Chapters II and III. On the right of the table is given the percentage of increase of the total maximum stresses by Chapter III over those by Chapter II; these range from 20 per cent. up to 96 per cent. for Column B, which receives its maximum stress under these loadings. Column A receives its maximum for wind on face A and similar percentages will be found for Column A under such loading. For example, for Column A–0, at $x = 0$ in., wind on face B, total maximum unit by Chapter II $= 13{,}879$ ℔ per sq. in., while by Chapter III the maximum unit is 16,680 ℔ per sq. in., being an increase of 20.2 per cent. (cf. 19.7 per cent. for Column B–0); also, for Column A–4, $x = 130$ in., the maximum by Chapter II $= 6{,}224$ ℔ per sq. in. while by Chapter III it is 12,652 ℔ per sq. in. or an increase of 103.3 per cent. (cf. 96.5 per cent. for Column B–4).

Section.	X	By Method of Chapter III.				By Method of Chapter II.				Per Cent. Increase.	All'd. Unit.
		Wind L'd.	Floor L'd.	Ecc. Col. L'd.	Total Max.	Wind L'd.	Floor L'd.	Ecc. Col. L'd.	Total Max.		
A–0	125	0	5,849	2,743	8,592	3,485	3,612	3,152	10,249		15,600
	0	5,220	2,349	3,349	10,918	3,485	3,612	3,152	10,249	6.5	15,600
B–0	125	5,745	5,847	3,145	14,737	7,315	3,612	3,512	14,439		15,600
	0	9,140	4,879	3,272	17,291	7,315	3,612	3,512	14,439	19.7	15,600
A–1	125	3,805	1,037	2,618	7,460	4,628	2,596	2,459	9,683		15,600
	0	4,175	466	2,823	7,464	4,628	2,596	2,459	9,683		15,600
B–1	125	7,474	5,774	3,422	16,670	7,303	3,658	3,704	14,665		15,620
	0	8,034	6,637	3,260	17,931	7,303	3,658	3,704	14,665	22.4	15,620
A–2	125	4,625	− 827	5,369	9,167	4,309	3,384	3,106	10,799		14,700
	0	4,220	924	3,871	9,015	4,309	3,384	3,106	10,799		14,700
B–2	125	6,455	5,605	1,216	13,276	6,494	2,708	2,461	11,663	13.8	15,620
	0	6,325	5,030	1,335	12,690	6,494	2,708	2,461	11,663		15,620
A–3	125	4,363	− 175	2,617	6,805	4,168	2,198	1,887	8,253		14,700
	0	3,693	−1,608	3,903	5,988	4,168	2,198	1,887	8,253		14,700
B–3	125	6,120	6,828	192	13,140	5,388	2,850	1,971	10,209	28.7	13,250
	0	5,035	7,088	93	12,216	5,388	2,850	1,971	10,209		13,250
A–4	130	0	8,140	373	8,513	2,905	1,736	1,143	5,784	47.2	6,890
	0	0	6,750	600	7,350	2,905	1,736	1,143	5,784		6,890
B–4	130	3,341	6,187	− 473	9,055	3,341	1,314	− 44	4,611	96.5	13,250
	0	3,011	4,575	− 535	7,051	3,341	1,314	− 44	4,611		13,250

The following table, compiled from those of Chapters VI, VIII, and IX gives a comparison of the total maximum stresses in the top flanges of the girders at the left end ($x = 200$ in.) by the methods of Chapters II and III. On the right is given the percentage of increase, as for the columns, and here also is found an ever-increasing divergence, from basement to roof, in the results by the two methods, ranging from 10 per cent. to 97 per cent. In the case of both columns and girders the main source of increase is due to the fact that the building is virtually a series of connected *arches* set vertically over each other and the vertical loads, both floor and eccentric column loads, are therefore to be regarded as producing stresses of very great importance in designing such structures. The wind produces stresses not materially different from those deduced for the rigid girder assumption. This merely confirms the demonstrations by Professor Howe, in which he shows that if a horizontal load acts in the neutral axis of the girders, as assumed in this investigation, the arch *thrust* is practically nil, *i. e.*, there is very little tendency of the feet of the supporting columns to move *with respect to each other*, but rather they tend to move the same amount, which condition would of course be in exact accord with the results on the assumption of rigid girders.

Girder.	Chapter III.	Chapter II.	Per Cent.
a–0	−126,884	−114,985	10.4
a–1	−106,764	− 92,103	16.0
a–2	− 84,552	− 66,205	27.8
a–3	− 66,874	− 44,151	51.5
a–4	− 37,633	− 19,095	97.0

CHAPTER X.

A STUDY OF COLUMN DEFLECTIONS AND DEFORMATIONS IN AN ELASTIC PORTAL BRACED BUILDING.

A. Distortion Due to Horizontal Wind Pressure.

In considering the effect of wind in distorting a portal braced structure the five story building already used will be investigated as follows:

First, as a *cantilever beam* fixed at one end and having a variable moment of inertia corresponding to the moment of inertia of the steel columns about a horizontal axis midway between the columns, the moment of inertia being considered as an average uniformly varying one from top to bottom.

Second, as a structure with *rigid girders*, corresponding to the assumptions of Chapter II.

Third, as a perfectly *elastic structure*, corresponding to the assumptions of Chapter III.

First. *As a Cantilever Beam.*—Referring to Fig. 10,

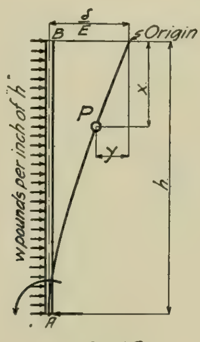


Fig 10

Let I = moment of inertia of the beam at B.

Let I_0 = moment of inertia of the beam at A.

Let I_x = moment of inertia of the beam at any point P.

Also let $I_x = I(1 + cx)$; then $I(1 + ch) = I_0$, or $c = \dfrac{I_0 - I}{hI}$.

Now, taking moments about $P \equiv (x, y)$ gives the fundamental equation

$$E\frac{d^2y}{dx^2} = \frac{wx^2}{2I_x} = \frac{w}{2I}\left(\frac{x^2}{1 + cx}\right) = \frac{w}{2Ic^2}\left[(cx - 1) + \frac{1}{cx + 1}\right];$$

integrating gives

$$E\frac{dy}{dx} = \frac{w}{2Ic^2}\left[\frac{cx^2}{2} - x + \frac{1}{c}\log_\epsilon (1 + cx) + K\right].$$

But, when $x = h, \dfrac{dy}{dx} = 0$; hence

$$K = -\frac{ch^2}{2} + h - \frac{1}{c}\log_\epsilon (1 + ch),$$

or

$$E\frac{dy}{dx} = \frac{w}{2Ic^2}\left[\frac{c}{2}(x^2 - h^2) - (x - h) + \frac{1}{c}\log_\epsilon \frac{1 + cx}{1 + ch}\right];$$

integrating again gives

$$Ey = \frac{w}{2Ic^2}\left\{\frac{cx}{6}(x^2 - 3h^2) - \frac{x}{2}(x - 2h) + \frac{1 + cx}{c^2}\log_\epsilon (1 + cx) - \frac{x}{c}[1 + \log_\epsilon(1 + ch)] + K'\right\}.$$

But, when $x = 0$, $y = 0$; hence $K' = 0$.

The equation for Ey or the elastic line is thus determined: Now for the five story building here considered the data required for determining this curve of distortion is as follows:

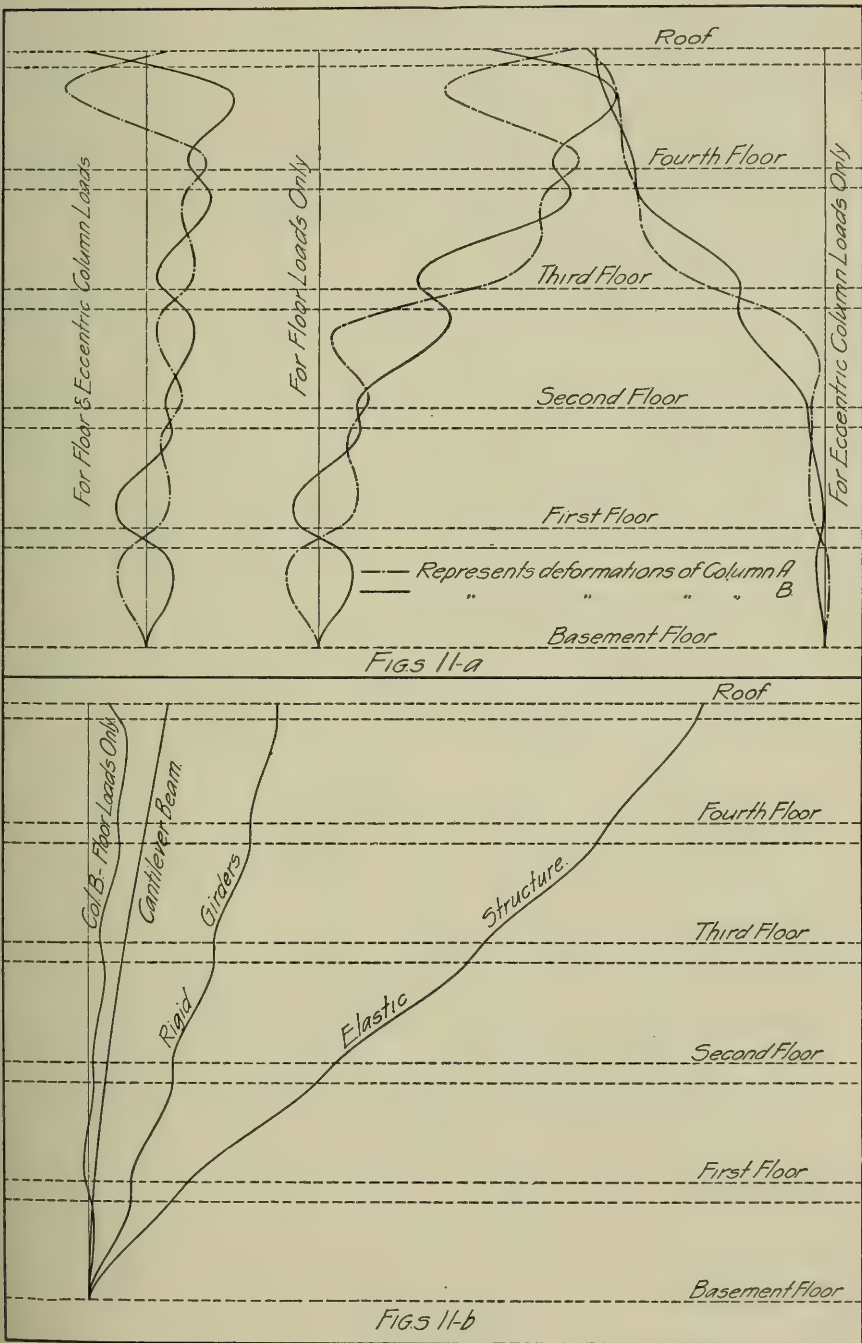
$$I_0 = 34.73 \times \overline{100}^2 \times 2 = 694{,}600. \quad I = (11.52 + 15.23) \times \overline{100}^2$$

$= 267{,}500$ (neglecting the comparatively small moments of inertia about the neutral axes of the columns).

$$h = 750 \text{ in.};$$

$w = 30.0$ ℔ $\times$ 20.0 ft. $\div$ $12 = 50$ ℔ per. inch of height of beam.

$$c = \frac{694{,}600 - 267{,}500}{750 \times 267{,}500} = 0.002135.$$


Roof
Fourth Floor
Third Floor
Second Floor
First Floor
Basement Floor
For Floor & Eccentric Column Loads
For Floor Loads Only
For Eccentric Column Loads Only
—·— Represents deformations of Column A
—— " " " " B
Figs 11-a
Roof
Fourth Floor
Third Floor
Second Floor
First Floor
Basement Floor
Col. B - Floor Loads Only
Cantilever Beam.
Rigid Girders
Elastic Structure.

Figs 11-b

Using these values in the value for Ey above, the deflection curve marked "cantilever beam" in Fig. 11–b, is obtained.

Second. As a Structure with Rigid Girders.—The values of δ for each story of the five story building may be calculated from the equation, Chapter II, $\delta = Sc^3/12I$. Since Columns A and B deflect equally, this equation may be applied to either column. Using the values of S given in Chapter II (or VI) the values of these deflections are;

$$\delta_0 = 1{,}730{,}000 \text{ in.}, \quad \delta_1 = 1{,}775{,}000 \text{ in.}, \quad \delta_2 = 1{,}765{,}000 \text{ in.},$$
$$\delta_3 = 1{,}505{,}000 \text{ in.}, \quad \delta_4 = 1{,}100{,}000 \text{ in.}$$

The distortion curve for this case is shown and marked "rigid girders" in Fig. 11–b.

Third. As an Entirely Elastic Structure.—The values of δ, C, and X coordinates of the points of contra-flexure for this case are given in Chapter VI, and the curves for Columns A and B fit so closely on each other that only that for Column A is shown in Fig. 11–b; this curve is marked "elastic structure."

B. DISTORTIONS DUE TO VERTICAL LOADING.

The values of δ, C, and X coordinates of the points of contra-flexure for uniform floor loading, eccentric column loading, and a combination of these two loadings, have been given in Chapters VIII, IX and VII respectively; by calculating, in addition, the slopes and deflections at the points of contra-flexure and a few other deflections as required, the deformation curves for these loadings have been constructed as shown in Figs. 11, a.

Fig. 11, b, also shows the curve for Column B for floor loads only. All curves of Figs. 11, a, are drawn to a horizontal scale of 1 in. = 1,000,000 in. while all those of Figs. 11, b, are drawn to a scale of .1 in. = 8,000,000 in. Notice in Figs. 11, a, the large distortions of the column *sections* due to floor loadings only.

CHAPTER XI.

A STUDY OF THE EFFECT OF HORIZONTAL AND VERTICAL LOADS ON A DOUBLE PLATE GIRDER PORTAL — WITH COMPARISONS.

This study is given to demonstrate the application of the general method of Chapter III to a structure of *three* columns per transverse section. The structure chosen for investigation is so selected as to also afford a test of the theory that the axial column unit stresses in a building subject to flexural forces, such as wind pressure, vary directly as the distance from a neutral axis. (See Chapter II.) The properties of the structure chosen are given in the following table marked "properties."

The structure will be investigated for two loadings; a horizontal wind pressure F_0^A equal to 10,000 lb, and a uniform load of 500 lb per inch of girder covering the entire structure, from Column A to Column C.

PROPERTIES.

Quant.	Value.	Quant.	Value.
c_0	100 in.	$A_0{}^B$	25
d_0	20 in.	$A_0{}^C$	10
b	200 in.	$I_0{}^a$	2,000
b'	100 in.	$I_0{}^b$	1,000
$I_0{}^A$	500	$A_0{}^a$	25
$I_0{}^B$	1,000	$A_0{}^b$	20
$I_0{}^C$	200	$F_0{}^A$	10,000
$A_0{}^A$	15	w_0	500

Now, from Plates IV to VIII inclusive, of Chapter III the values of the symbolic coefficients for forming the equations for this case may be easily computed. The solution for both loadings will be carried through in one set of tables as was done in Chapter VI. The values of these symbolic coefficients then are as given in the table on page 160.

Now, using these symbolic coefficients, the solution given in Plates 11 and 12 may be calculated. The term "ω" of Plate 12 will contain only the constant terms "z," since the structure

Exp'n.	Values of Symbolic Coefficients.						z_0	
	a_0	b_0	c_0	i_0	j_0	o_0	For F_0A.	For W_0.
$C-A$	+ 0.200000	0	0	− 10.00000	0	0	0	0
$C-B$	0	+ 0.100000	0	0	− 5.00000	0	0	0
$C-C$	0	0	+ 0.500000	+ 25.00000	+ 25.00000	0	− 250,000	0
$\delta-A$	+10.00000	0	0	− 333.333	0	0	0	0
$\delta-B$	0	+ .000000	0	0	− 166.6666	0	0	0
$\delta-C$	0	0	+25.00000	+ 833.333	+ 833.3333	0	− 8,333,333	0
$H-a$	0	0	0	− 1.00000	0	0	+ 10,000	0
$H-b$	0	0	0	− 1.00000	− 1.00000	0	+ 10,000	0
$\lambda-a$	0	0	0	− 8.00000	0	0	+ 80,000	0
$a-b$	0	0	0	− 5.00000	− 5.00000	0	+ 50,000	0
$V-A$	+ 0.0033333	+ 0.003333	+ 0.0033333	0	0	− 0.33333	− 3,667	+ 75,000
$V-C$	− 0.0033333	− 0.003333	− 0.0033333	0	0	− 0.66666	+ 3,667	+ 75,000
$\alpha-A$	+ 0.024444	+ 0.024444	+ 0.024444	0	0	− 2.44444	− 26,900	+ 550,000
$\alpha-B$	0	0	0	0	0	+ 4.40000	0	0
$\alpha-C$	− 0.036666	− 0.036666	− 0.036666	0	0	− 7.33333	+ 40,333	+ 825,000
$\Delta-a$	− 0.024444	− 0.024444	− 0.024444	0	0	+ 6.84444	+ 26,900	− 550,000
$\Delta-b$	− 0.036666	− 0.036666	− 0.036666	0	0	− 11.73333	+ 40,333	+ 825,000
$Q-a$	− 0.0005000	0	0	+ 0.055000	0	0	0	0
$Q-b$	− 0.0003333	− 0.0003333	+ 0.0006666	+ 0.110000	+ 0.110000	− 0.066666	− 733.33	+ 5,000
$R-a$	+ 0.000001666	+ 0.000001666	+ 0.000001666	0	0	− 0.00016666	− 1.83333	+ 37.5
$R-b$	+ 0.000003333	+ 0.000003333	+ 0.000003333	0	0	+ 0.0006666	− 3.66666	− 25.0
$A-a$	+12.00000	− 6.00000	0	− 425.3333	+ 216.6666	0	− 80,000	0
$A-b$	0	+ 6.00000	−30.00000	−1,078.3333	−1,295.000	0	+10,783,333	0
$B-a$	− 0.266666	+ 0.133333	+ 0.033333	+ 21.00000	− 5.00000	− 3.33333	− 36,667	+ 416,667
$B-b$	− 0.016666	− 0.116666	+ 0.583333	+ 36.00000	+ 41.00000	− 3.33333	− 341,667	+ 291,667
$C-a$	− 5.531111	+24.468888	+ 4.468888	+1,100.0000	−1,000.0000	−451.2888	− 4,915,788	+50,550,000
$C-b$	− 0.518888	− 0.518888	+54.481111	+3,050.0000	+3,050.0000	− 99.378	−29,929,222	+ 9,591,661

Equation.	α	β	γ	θ	ϕ	ϵ	ω For F_0A.	ω For W_0.
A–a–1	+12.000000	− 6.000000	0	− 425.3333	+ 216.6666	0	− 80,000	0
A–b–1	0	+ 6.000000	− 30.000000	− 1,078.3333	− 1,295.0000	0	+10,783,333	0
B–a–1	− 0.266666	+ 0.133333	+ 0.033333	+ 21.00000	− 5.000000	− 3.333333	− 36,667	+ 416,667
B–b–1	− 0.016666	− 0.116666	+ 0.583333	+ 36.00000	+ 41.000000	− 3.333333	− 341,667	+ 291,667
C–a–1	− 5.531111	+24.468888	+ 4.468888	+ 1,100.0000	− 1,000.0000	− 451.289	− 4,915,788	+ 50,550,000
C–b–1	− 0.518888	− 0.518888	+ 54.481111	+ 3,050.0000	+ 3,050.0000	− 99.378	−29,929,222	+ 9,591,661
	M_0A	+ 0.500000	0	+ 35.4444	− 18.05555	0	+ 6,666.666	0
	A–b–2	+ 6.000000	− 30.00000	− 1,078.3333	− 1,295.0000	0	+10,783,333	0
	B–a–2	0	+ 0.033333	+ 11.548148	− 0.18518518	− 3.333333	− 38,444.44	+ 416,667
	B–b–2	−0.1250000	+ 0.583333	+ 35.409259	+ 41.3009259	− 3.333333	− 341,777.77	+ 291,667
	C–a–2	+21.703333	+ 4.468888	+ 903.953	− 900.133	− 451.289	− 4,952,663	+ 50,550,000
	C–b–2	− 0.778333	+ 54.481111	+ 3,031.608	+ 3,059.3688	− 99.378	−29,932,681	+ 9,591,661
		M_0B	+ 5.000000	+ 179.72222	+ 215.8333	0	− 1,797,222	0
		B–a–3	+ 0.033333	+ 11.548148	− 0.18518518	− 3.333333	− 38,444.44	+ 416,667
		B–b–3	− 0.041666	+ 12.943981	+ 14.321759	− 3.333333	− 117,125.00	+ 291,667
		C–a–3	+112.98555	+ 4,804.523	+ 3,784.17	− 451.289	−43,958,363	+ 50,550,000
		C–b–3	+ 50.589444	+ 2,891.724	+ 2,891.378	− 99.378	−28,533,841	+ 9,591,661
			M_0C	− 346.4444	+ 5.55555	+ 100.0000	+ 1,153,333	− 12,500,000
			B–b–4	+ 27.379166	+ 14.090278	− 7.500000	− 165,180.5	+ 812,500.00
			C–a–4	−34,338.69	+ 4,411.87	+10,847.266	+86,351,637	−1,361,759,377
			C–b–4	−14,634.71	+ 3,172.43	+ 4,959.565	+29,812,639	− 622,776,389
				S_0A	− 0.514635	+ 0.273931	+ 6,033.076	− 29,675.84
				C–a–5	+22,083.8	+ 1,440.84	−120,816,363	− 342,729,400
				C–b–5	+10,703.96	+ 950.67	−58,479,661	− 188,479,400
					S_0B	− 0.0652442	+ 5,470.82	+ 15,519.5
					C–b–6	+ 252.30	+ 79,739	− 22,359,400
						V_0B	− 316.05	+ 88,622.3

consists of only one story. The calculations were carried out by Vega's logarithmic tables, because only a rough value of V_0^B can be obtained with a Thacher rule, the solution involving the differences of large quantities of very nearly the same size. The calculations are given in the table on page 161.

Now, from this table and the table of symbolic coefficients the values of all quantities may be written out as follows:

For the Wind Pressure F_0^A.—

$V_0^B = -316.05$ lb.

$S_0^B = -0.0652442\ V_0^B + 5{,}470.82 = +5{,}491.44$ lb.

$S_0^A = -0.514635\ S_0^B + 0.273931\ V_0^B + 6{,}033.076 = +3{,}120.41$ lb.

$M_0^C = -346.444\ S_0^A + 5.5555\ S_0^B + 100.0000\ V_0^B + 1{,}153{,}333$
$= +71{,}186$ in. lb.

$M_0^B = +5.0000\ M_0^C + 179.7222\ S_0^A + 215.8333\ S_0^B + 0\ V_0^B$
$- 1{,}797{,}222 = +304{,}755$ in. lb.

$M_0^A = +0.50000\ M_0^B + 0\ M_0^C + 35.4444\ S_0^A - 18.0555\ S_0^B$
$+ 0\ V_0^B + 6{,}667 = +170{,}495$ in. lb.

$S_0^C = 10{,}000 - S_0^A - S_0^B = +1{,}388.15$ lb.

$X_0^A = 170{,}495 \div 3{,}120.4 = +54.67$ in.;

$X_0^B = 304{,}755 \div 5{,}491.44 = +55.52$ in.;

$X_0^C = 71{,}186 \div 1{,}388.15 = +51.25$ in.

$C_1^A = +0.2\ M_0^A - 10.0\ S_0^A = +2{,}894.9.$

$C_1^B = +0.1\ M_0^B - 5.0\ S_0^B = +3{,}018.3.$

$C_1^C = +0.5\ M_0^C + 25.0\ (S_0^A + S_0^B) - 250{,}000 = +8{,}892.$

$\delta_0^A = +10.0\ M_0^A - 333.33\ S_0^A = +664{,}813$ in.

$\delta_0^B = +5.0\ M_0^B - 166.66\ S_0^B = +608{,}535$ in.

$\delta_0^C = +25.0\ M_0^C + 833.33\ (S_0^A + S_0^B) - 8{,}333{,}333$
$= +622{,}859$ in.

$H_0^a = -1.0\ S_0^A + 10{,}000 = +6{,}879.59$ lb.

$H_0^b = -1.0\ (S_0^A + S_0^B) + 10{,}000 = +1{,}388.15$ lb.

$\lambda_0^a = -8.0\ S_0^A + 80{,}000 = +55{,}037$ in.

$\lambda_0^b = -5.0\ (S_0^A + S_0^B) + 50{,}000 = +6{,}941$ in.

$V_0^A = +0.003333\ (M_0^A + M_0^B + M_0^C) - 0.3333\ V_0^B - 3{,}666.7$
$= -1{,}739.9$ lb.

$$V_0^C = -0.003333\,(M_0^A + M_0^B + M_0^C) - 0.6666\,V_0^B + 3{,}666.7$$
$$= +2{,}056.0 \text{ lb.}$$

$$\alpha_0^A = +0.02444\,(M_0^A + M_0^B + M_0^C) - 2.4444\,V_0^B - 26{,}900$$
$$= -12{,}770 \text{ in.}$$

$$\alpha_0^B = +4.400\,V_0^B = -1{,}390 \text{ in.}$$

$$\alpha_0^C = -0.03666\,(M_0^A + M_0^B + M_0^C) - 7.3333\,V_0^B + 40{,}333$$
$$= +22{,}600 \text{ in.}$$

$$\Delta_0^a = -0.02444\,(M_0^A + M_0^B + M_0^C) + 6.845\,V_0^B + 26{,}900$$
$$= +11{,}380 \text{ in.}$$

$$\Delta_0^b = -0.036667\,(M_0^A + M_0^B + M_0^C) - 11.7333\,V_0^B + 40{,}333$$
$$= +23{,}990 \text{ in.}$$

Checks.

$$\left.\begin{aligned} \delta_0^A + 10.0\,C_1^A - \lambda_0^a &= +638{,}725 \text{ in.} \\ \delta_0^B + 10.0\,C_1^B \qquad &= +638{,}718 \text{ in.} \end{aligned}\right\} \text{Checks.}$$

$$\left.\begin{aligned} \delta_0^B + 10.0\,C_1^B - \lambda_0^b &= +631{,}777 \text{ in.} \\ \delta_0^C + 10.0\,C_1^C \qquad &= +631\ 751 \text{ in.} \end{aligned}\right\} \text{Checks.}$$

For the Floor Load w_0.—

$$V_0^B = +88{,}622.3 \text{ lb.}$$

$$S_0^B = -0.065244\,V_0^B + 15{,}519.5 = +9{,}737.4 \text{ lb.}$$

$$S_0^A = -0.514635\,S_0^B + 0.273931\,V_0^B - 29{,}675.8 = -10{,}410.6 \text{ lb.}$$

$$M_0^C = -346.444\,S_0^A + 5.5555\,S_0^B + 100.000\,V_0^B - 12{,}500{,}000$$
$$= +23{,}017 \text{ in. lb.}$$

$$M_0^B = +5.00000\,M_0^C + 179.722\,S_0^A + 215.833\,S_0^B + 0\,V_0^B + 0$$
$$= +345{,}720 \text{ in. lb.}$$

$$M_0^A = +0.5000\,M_0^B + 0\,M_0^C + 35.444\,S_0^A - 18.0555\,S_0^B + 0\,V_0^B$$
$$+ 0 = -371{,}952 \text{ in. lb.}$$

$$S_0^C = 0 - S_0^A - S_0^B = +673.2 \text{ lb.}$$

$$X_0^A = -371{,}952 \div -104{,}106 = +35.73 \text{ in.};$$

$$X_0^B = 345{,}720 \div 9{,}737.4 = +35.51 \text{ in.};$$

$$X_0^C = +23{,}017 \div 673.2 = +34.21 \text{ in.}$$

$$C_1^A = +0.2\,M_0^A - 10.0\,S_0^A + = 29{,}715.6$$

$$C_1^B = +0.1\,M_0^B - 5.0\,S_0^B = -14{,}115.0.$$

$$C_1^C = +0.5\,M_0^C + 25.0\,(S_0^A + S_0^B) = -5{,}321.5.$$

$\delta_0^A = +10.0\ M_0^A - 333.333\ S_0^A = -249{,}320$ in.

$\delta_0^B = +5.0\ M_0^B - 166.667\ S_0^B = +105{,}700$ in.

$\delta_0^C = +25.0\ M_0^C + 833.333\ (S_0^A + S_0^B) = +14{,}425$ in.

$H_0^a = -1.0\ S_0^A = +10{,}410.6$ lb.

$H_0^b = -1.0\ (S_0^A + S_0^B) = +673.2$ lb.

$\lambda_0^a = -8.0\ S_0^A = +83{,}285$ in.

$\lambda_0^b = -5.0\ (S_0^A + S_0^B) = +3{,}366$ in.

$V_0^A = +0.003333\ (M_0^A + M_0^B + M_0^C) - 0.3333\ V_0^B + 75{,}000 = +45{,}448$ lb.

$V_0^C = -0.003333\ (M_0^A + M_0^B + M_0^C) - 0.6666\ V_0^B + 75{,}000 = +15{,}930$ lb.

$\alpha_0^A = +0.02444\ (M_0^A + M_0^B + M_0^C) - 2.4444\ V_0^B + 550{,}000 = +333{,}289$ in.

$\alpha_0^B = +4.400\ V_0^B = +389{,}938$ in.

$\alpha_0^C = -0.036666\ (M_0^A + M_0^B + M_0^C) - 7.3333\ V_0^B + 825{,}000 = +175{,}221$ in.

$\Delta_0^a = -0.024440\ (M_0^A + M_0^B + M_0^C) + 6.845\ V_0^B - 550{,}000 = +56{,}649$ in.

$\Delta_0^b = -0.036666\ (M_0^A + M_0^B + M_0^C) - 11.7333\ V_0^B + 825{,}000 = -214{,}717$ in.

Maximum bending in columns occurs at the top. The values are:

For Col. A $-\ 100\ S_0^A + M_0^A = +669{,}108$ in. lb.

For Col. B $-\ 100\ S_0^B + M_0^B = -628{,}020$ in. lb.

For Col. C $-\ 100\ S_0^C + M_0^C = -\ \ 44{,}303$ in. lb.

Checks:

$$\left.\begin{array}{ll} \delta_0^A + 10.0\ C_1^A - \lambda_0^a = & -35{,}449 \text{ in.} \\ \delta_0^B + 10.0\ C_1^B = & -35{,}450 \text{ in.} \end{array}\right\}\text{Checks.}$$

$$\left.\begin{array}{ll} \delta_0^B + 10.0\ C_1^B - \lambda_0^b = & -38{,}816 \text{ in.} \\ \delta_0^C + 10.0\ C_1^C = & -38{,}790 \text{ in.} \end{array}\right\}\text{Checks.}$$

The stresses and deformations will now be computed by the methods of Chapter II.

For Wind Load F_0^A.—

$$h^A = \frac{200 \times 25 + 300 \times 10}{15 + 25 + 10} = + 160.00 \text{ in.}$$

$$X = + 10{,}000 \times 60.0 = + 600{,}000 \text{ in. lb.}$$

$$s[15 \times \overline{160}^2 + 25 \times \overline{40}^2 + 10 \times \overline{140}^2] = + 600{,}000;$$

hence

$$s = + 0.967741 \text{ lb.} \quad s_0^A = - 160\, s = - 154.838 \text{ lb.};$$

$$s_0^B = + 40\, s = + 38.709 \text{ lb.}; \quad s_0^C = + 140\, s = + 135.484 \text{ lb.}$$

$$V_0^A = 15\, s_0^A = - 2{,}322.5 \text{ lb.}; \quad V_0^B = 25\, s_0^B = + 967.7 \text{ lb.};$$

$$V_0^C = 10\, s_0^C = + 1{,}354.8.$$

$$S_0^A = \tfrac{500}{1700} \times 10{,}000 = + 2{,}941.2 \text{ lb};$$

$$S_0^B = \tfrac{1000}{1700} \times 10{,}000 = + 5{,}882.3 \text{ lb};$$

$$S_0^C = \tfrac{200}{1700} \times 10{,}000 = + 1{,}176.5 \text{ lb.}$$

$$C_1^A = C_1^B = C_1^C = 0; \quad X_0^A = X_0^B = X_0^C = + 50.0;$$

$$\delta_0^A = \delta_0^B = \delta_0^C = \frac{5882.3 \times \overline{100}^3}{12{,}000} = + 491{,}860 \text{ in.}$$

$$M_0^A = 50.0\, S_0^A = + 147{,}060 \text{ in. lb.}$$

$$M_0^B = 50.0\, S_0^B = + 294{,}115 \text{ in. lb.}$$

$$M_0^C = 50\, S_0^C = + 58{,}825 \text{ in. lb.}$$

For Floor Load w_0.—

$$h^A = 160.0 \text{ in.}; \quad X = - 500 \times 300 \times 10 = - 1{,}500{,}000 \text{ in. lb.}$$

$$s[15 \times \overline{160}^2 + 25 \times \overline{40}^2 + 10 \times \overline{140}^2] = - 1{,}500{,}000; \quad \text{hence}$$

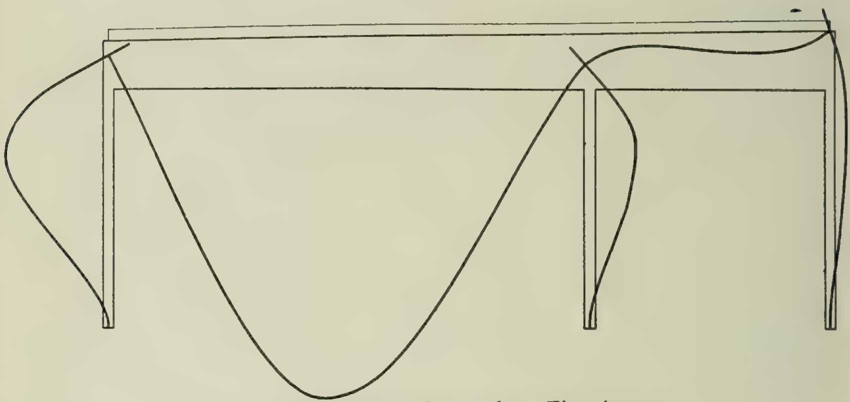
$$s = - 2.41935 \text{ lb.}$$

$$s_0^A = - 160.0\, s = + 387.095 \text{ lb}; \quad s_0^B = + 40\, s = - 96.773 \text{ lb};$$

$$s_0^C = + 140\, s = - 338.71 \text{ lb.}$$

$$p = \frac{500 \times 300}{15 + 25 + 10} = + 3{,}000 \text{ lb}, \quad p = + 3{,}000 \text{ lb},$$

$$p = + 3{,}000 \text{ lb.}$$

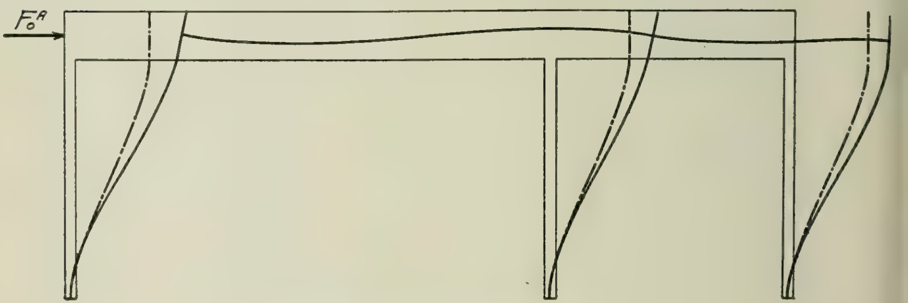


Deformation for Uniform Floor Load w_0.

—·— Deformation by method of Chapter II.

—— " " " " " III.

All deformations are shown to the same scale.



Deformation for Wind Load F_0^A

FIGS 12.

$$\text{Resultants:}\quad s_0^A = +\,3{,}387.095 \text{ lb per sq. in.}$$

$$s_0^B = +\,2{,}903.227 \text{ lb per sq. in.,}$$

$$s_0^C = +\,2{,}661.29 \text{ lb per sq. in.}$$

$$V_0^A = 15\, s_0^A = +\,50{,}806.4 \text{ lb;}$$

$$V_0^B = 25.0\, s_0^B = +\,72{,}580.7 \text{ lb;}$$

$$V_0^C = 10\, s_0^C = +\,26{,}612.9 \text{ lb.}$$

$$S_0^A = S_0^B = S_0^C = 0; \quad M_0^A = M_0^B = M_0^C = 0;$$

$$C_1^A = C_1^B = C_1^C = 0; \quad \delta_0^A = \delta_0^B = \delta_0^C = 0.$$

Now, for a more comprehensive comparison the results of the calculations of this chapter are arranged in tabular form as follows:

	For Wind Load F_0^A.		For Floor Load W_0.	
	Chapter III.	Chapter II.	Chapter III.	Chapter II.
S_0^A	+ 3,120.4	+ 2,941.2	− 10,410.6	0
S_0^B	+ 5,491.4	+ 5,882.3	+ 9,737.4	0
S_0^C	+ 1,388.2	+ 1,176.5	+ 673.2	0
V_0^A	− 1,739.9	− 2,322.5	+ 45,448	+50,806.4
V_0^B	− 316.1	+ 967.7	+ 88,622.3	+72,580.7
V_0^C	+ 2,056.0	+ 1,354.8	+ 15,930	+26,612.9
M_0^A	+170,495	+147,060	−371,952	0
M_0^B	+304,755	+294,115	+345,720	0
M_0^C	+ 71,186	+ 58,825	+ 23,017	0
X_0^A	+ 54.67	50.0	+ 35.73	0
X_0^B	+ 55.52	50.0	+ 35.51	0
X_0^C	+ 51.25	50.0	+ 34.21	0
δ_0^A	+664,813	+491,860	−249,320	0
δ_0^B	+608,535	+491,860	+105,700	0
δ_0^C	+622,859	+491,860	+ 14,425	0
Max. M^A	+170,495	+147,060	+669,108	0
Max. M^B	+304,755	+294,115	−628,020	0
Max. M^C	+ 71,186	+ 58,825	− 44,303	0

A graphical comparison of distortions is shown in Figs. 12.

CHAPTER XII.

THE DESIGNING OF KNEE BRACED STRUCTURES.

In this chapter the knee brace is considered as an elastic member with pivoted connections at each end.

In the segment ACB of the knee braced column shown in Fig. 13, *a*, suppose B to be the point of contraflexure, *i. e.*, that no bending moment exists at this point. The external forces acting on the segment ABC will then consist of the shear S, applied at B, the knee brace stress applied at C, and a bending moment and horizontal force at A to maintain equilibrium and keep the column vertical at A. In addition to these forces there exists the axial load on the column but, in all these discussions the effect of the axial load on the bending of the column is neglected. The effect of the shearing force S and the knee brace stress will be considered separately.

For the Shearing Force S.—Referring to Fig. 13, *a*,

$$M = Sa; \quad M_x = M - Sx = S(a - x).$$

This gives, for the elastic line

$$E\frac{d^2y}{dx^2} = \frac{S}{I}(a - x);$$

hence

$$E\frac{dy}{dx} = \frac{Sx}{I}\left(a - \frac{x}{2}\right);$$

and

$$Ey = \frac{Sx^2}{2I}\left(a - \frac{x}{3}\right);$$

both constants of integration being zero. Thus the deflection at the knee brace connection at C is given by

$$\delta_c = Ey_c = \frac{Sx_c^2}{2I}\left(a - \frac{x_c}{3}\right).$$

For the Stress in the Knee Brace.—Referring to Fig. 13, *b*, it is

seen that

$$\delta'_c = Ey'_c = \frac{Px_c^3}{3I};$$

since the case is simply the deflection under a concentrated load applied at the end of a cantilever beam of length equal to X_c.

The Resultant Deflection at C.—Evidently C will deflect under the combined action of these forces to the right an amount measured by

$$\delta''_c = \delta_c - \delta'_c = Ey''_c = \frac{Sx_c^2}{2I}\left(a - \frac{x_c}{3}\right) - \frac{Px_c^3}{3I}.$$

Solution for Knee Brace Stress.—Referring to Fig. 13, *c*. Let the floor girder A–D be considered perfectly rigid. The knee brace CD then, after distortion, assumes the position $C'D$ where

$$CC' = \frac{\delta''_c}{E};$$

the shortening, CE of the knee brace will be equal to

$$\frac{\delta''_c}{E}\frac{n}{m} = \frac{\lambda}{E}.$$

The force P is the horizontal component of the knee brace stress; therefore, the stress in the brace is $P\ m/n$. Now let A_k be the cross sectional area of the knee brace. Then

$$\lambda = \frac{Pm^2}{nA_k};$$

but

$$\lambda = \delta''_c\frac{n}{m};$$

hence

$$\frac{Pm^2}{nA_k} = \delta''_c\frac{n}{m}$$

or

$$\delta''_c = P\frac{m^3}{n^2A_k} = S\frac{x_c^2}{2I}\left(a - \frac{x_c}{3}\right) - P\frac{x_c^3}{3I}$$

or

$$P\left[\frac{m^3}{n^2A_k} + \frac{x_c^3}{3I}\right] = S\frac{x_c^2}{2I}\left(a - \frac{x_c}{3}\right).$$

Designing.—Referring to the above formula, it is very evident that the larger A_k becomes, *i. e.*, the greater the cross sectional area

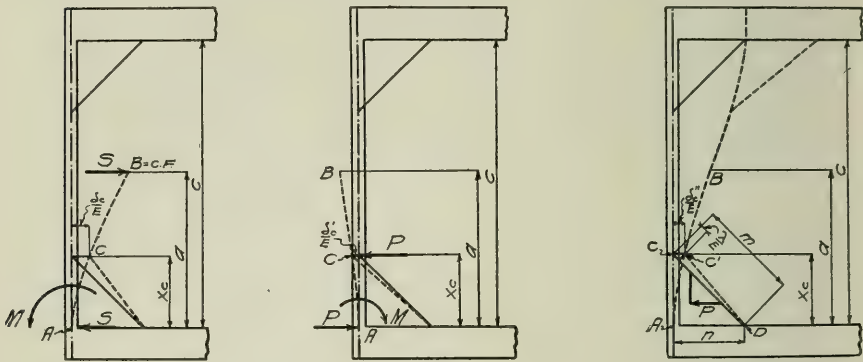


Fig 13-a Fig. 13-b Fig. 13-c

of the knees, the larger the total stress in the knee becomes also, and δ''_c approaches more nearly to the value zero. δ''_c cannot, however, reach as low as zero, for this would imply an infinite value of A_k. Now, if it is desired to so determine A_k that the allowed unit stress in the brace will not be exceeded, let s be the unit stress allowed; then

$$s = P\frac{m}{nA_k}$$

or

$$s = \frac{S\dfrac{x_c^2}{2I}\left(a - \dfrac{x_c}{3}\right)m}{nA_k\left[\dfrac{m^3}{n^2A_k} + \dfrac{x_c^3}{3I}\right]}$$

or

$$A_k\left[\frac{m^3}{n^2A_k} + \frac{x_c^3}{3I}\right] = S\frac{mx_c^2}{2nIs}\left(a - \frac{x_c}{3}\right)$$

or

$$A_k = \frac{3I}{x_c^3}\left[S\frac{mx_c^2}{2nIs}\left(a - \frac{x_c}{3}\right) - \frac{m^3}{n^2}\right].$$

Applications.—In applying these formulae the first thing to decide on is what value shall be assigned for "a." The value of "a" will depend on what type of loading produces the bending in

the column and also, to some extent, on the disposition of the bracing. It has been shown in previous chapters that, for all kinds of loading the position of the point of contraflexure does not follow any simple law, but is quite variable; however, when the bending is due to wind pressure, for all stories above the basement it is fairly close to take $a = c/2$ *when no knees are used.* For other loadings it would be much wiser to assume $a = \frac{5}{8}c$.

Now, if similar knees are used at both top and bottom of the column section, then, evidently, the values above will not be altered any. This, however, is not often a practicable way to brace a building, except in the end or wall sections of the building, because of the interference of the knee with the floor space. When knees are used only at the top (or bottom) the assumptions above will also hold quite well, as will be shown a little later.

Now, as an example, assume the following data:

S = 16,000 lb; c = 125 in.; x_c = 36 in. = n; m = 1.414;
n = 50.85 in. (45° bracing); I = 1,550; s = 15,000 lb per sq. in.;

assume $a = c/2 = 62.5$ in.

Solving for A_k gives

$$A_k = \frac{3 \times 1{,}550}{36^3}\left[16{,}000 \times \frac{50.85 \times \overline{36^2} \times 50.5}{72 \times 1{,}550 \times 15{,}000} - \frac{\overline{50.85^3}}{36^2}\right] = -6.94 \text{ sq. in.}$$

This is an impossible area of cross-section.

Evidently the maximum unit stress which can exist in the brace will occur when A_k is a minimum. Making $A_k = 0$, *i. e.*, no brace,

$$s = \frac{Snx_C^2\left(a - \dfrac{x_c}{3}\right)}{2m^2I} = \frac{16{,}000 \times 36 \times \overline{36^2} \times 50.5}{2 \times 50.85^2 \times 1{,}550} = 4{,}720 \text{ lb per sq. in.}$$

This is then the stress that would exist if the brace were but a thin wire (tension brace) and no greater stress will exist. Certainly then, *so far as the brace is concerned*, it carries stress at a remarkably uneconomical unit.

Now, assume the brace to consist of 2 ∠'s $3\frac{1}{2}$ in. x 3 in. x $\frac{3}{8}$ in.;

then A_k = 4.60 sq. in. gross or 4.04 sq. in. net say; then

$$s = \frac{16{,}000 \times \overline{36}^2 \times \overline{50.85} \times 50.5}{72 \times 1{,}550 \times 54.04 \left[\frac{\overline{50.85}^3}{36^2 \times 4.04} + \frac{\overline{36}^3}{3 \times 1{,}550} \right]}$$
$$= 3{,}360 \text{ lb per sq. in.}$$

Effect of Knee Bracing on Columns.—Using the angle bracing just mentioned gives

$$P \left[\frac{\overline{50.85}^3}{36^2 \times 4.04} + \frac{\overline{36}^3}{3 \times 1{,}550} \right] = \frac{16{,}000 \times \overline{36}^2 \times 50.5}{2 \times 1{,}550}$$

or

$$P = \frac{337{,}500}{35.15} = 9{,}610 \text{ lb.}$$

$$\delta_c = \frac{16{,}000 \times \overline{36}^2 \times 50.5}{2 \times 1{,}550} = 337{,}500 \text{ in.,}$$

$$\delta_c' = \frac{9{,}610 \times \overline{36}^3}{3 \times 1{,}550} = 96{,}100 \text{ in.;}$$

hence

$$\delta_c'' = 337{,}500 - 96{,}100 = 241{,}400 \text{ in.}$$

or

$$y_c'' = \frac{241{,}400}{28{,}000{,}000} = 0.00861 \text{ in.;} \quad M' = 36 \times 9{,}610 = 346{,}000 \text{ in. lb.;}$$

$$M = 62.5 \times 16{,}000 = 1{,}000{,}000 \text{ in. lb.}$$

Maximum resultant bending moment in column equals, 1,000,000 − 346,000 = 654,000 in. lb. Thus the deflection will be reduced 28.6 per cent. at the brace and the maximum bending in the column will be reduced 34.6 per cent. *if the knees* are used at both top and bottom; if used only at the top the maximum bending occurs at the bottom and equals 16,000 × 62.5 = 1,000,000 in. lb. and no saving of material but rather a waste would seem to be indicated; however, the brace serves to stiffen the girders.

Discussion.—Professor Heller in his "Stresses in Structures" has derived very complete formulae for portals of different types. For the type used in the above calculations, viz., a rigid girder with knee bracing, it is assumed that the brace is perfectly rigid, *i. e.*,

that C, Fig. 14, remains vertically under BD and the flexure curve is then as shown in the figure in solid lines. The bending moment at B is thus *reversed* from what would have existed had there been no knees. It is shown in the above calculations that the curve of flexure would be as indicated in the figure by the broken line, the effect of the knees being merely to reduce the deflection at C and the bending at B as noted above. Professor Heller shows that, for his assumptions,

$$c - a = \frac{a'(a' + c)}{3a' + c};$$

thus when $a' = 9/10\ c$, $a = 0.537\ c$ and when $a' = 0.5\ c$, $a = 0.7\ c$.

In order to determine about what the value of a should be when the knees are placed only at top or bottom, the formulae will now

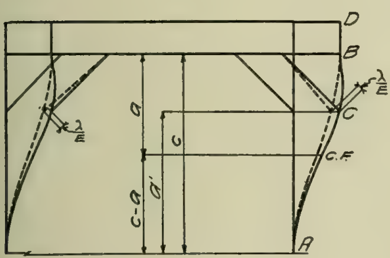


FIG. 14.

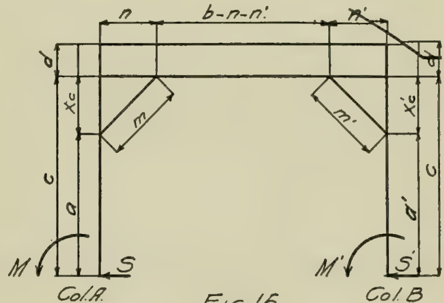


FIG. 15.

be derived for a knee braced plate girder portal, assuming the girder as rigid but the braces as elastic and with pivoted connections.

Referring now to Fig. 15,

For Column A,

$$EI\frac{d^2y}{dx^2} = M - Sx + P(x - a)_a^c,$$

$$EI\frac{dy}{dx} = Mx - \tfrac{1}{2}Sx^2 + P\left(\frac{x^2}{2} - ax\right)_a^c + C,$$

$$EIy = \tfrac{1}{2}Mx^2 - \tfrac{1}{6}Sx^3 + P\left(\frac{x^3}{6} - \frac{ax^2}{2}\right)_a^c + Cx + C'.$$

From $x = 0$ to $x = a$

$$EI\frac{dy}{dx} = Mx - S\frac{x^2}{2}$$

and

$$EIy = \tfrac{1}{2}Mx^2 - \tfrac{1}{6}Sx^3.$$

From $x = a$ to $x = c$

$$C = +P\frac{a^2}{2}$$

and

$$C' = -P\frac{a^3}{6};$$

hence

$$EI\frac{dy}{dx} = Mx - \tfrac{1}{2}Sx^2 + P\left(\frac{x^2}{2} - ax\right) + P\frac{a^2}{2}$$

and

$$EIy = \tfrac{1}{2}Mx^2 - \tfrac{1}{6}Sx^3 + P\left(\frac{x^3}{6} - \frac{ax^2}{2}\right) + P\frac{a^2x}{2} - P\frac{a^3}{6}.$$

Now, when $x = C$, $dy/dx = 0$; hence, substituting and solving gives

$$M = \tfrac{1}{2}Sc - P\frac{(c-a)^2}{2c}.$$

Similarly for Column B,

$$M' = \tfrac{1}{2}S'c - P'\frac{(c-a')^2}{2c}.$$

Also, when $x = c$, δ for Column $A = \delta$ for Column B since the girder is rigid, but δ for Column A

$$= Ey = \frac{Sc^3}{12I} - \frac{P(c-a)^2(c+2a)}{12I}$$

and similarly δ for Column B

$$= \frac{S'c^3}{12I'} - \frac{P'(c-a')^2(c+2a')}{12I'};$$

equating δ for Column A to δ for Column B and solving gives

$$Sc^3\left(1 + \frac{I}{I'}\right) = P(c-a)^2(c+2a) - P'\frac{I}{I'}(c-a')^2(c+2a') + Fc^3\frac{I}{I'}$$

since $S' = F - S$.

When $x = a$,

$$Ey = \frac{Ma^2}{2I} - \frac{Sa^3}{6I}$$

and, substituting the value of M obtained above, gives

$$Ey = \frac{Sa^2}{12I}(3c - 2a) - \frac{Pa^2}{12I}\left[\frac{3(c-a)^2}{c}\right].$$

Now the value of $\delta c''$, of the early part of this chapter, will equal the difference between the values of Ey for $x = c$ and for $x = a$; making the substitutions gives $\delta c''$, for Column A

$$= \frac{1}{12I}\left\{Sc^3 - P(c-a)^2(c+2a) - Sa^2(3c-2a) + 3P\frac{a^2(c-a)^2}{c}\right\};$$

but

$$\delta c'' = \frac{Pm^3}{n^2A_k}$$

hence solving, gives

$$P\left\{\frac{m^3}{n^2A_k} + \frac{(c-a)^3(3a+c)}{12cI}\right\} = S\frac{(c^3 - 3ca^2 + 2a^3)}{12I},$$

and similarly may be obtained for Column B the value

$$P'\left\{\frac{m'^3}{n'^2A_k'} + \frac{(c-a')^3(3a'+c)}{12cI'}\right\} = S'\frac{(c^3 - 3ca'^2 + 2a'^3)}{12I'}.$$

Now, substituting these values of P and P' in terms of S, in the value given for S above determines S and thence P, P', S', M and M' and all other unknowns.

When the structure is symmetrical the results reduce to

$$S = S' = \tfrac{1}{2}F$$

and

$$P = P' = \frac{(c^3 - 3a^2c + 2a^3)}{12I\left[\frac{m^3}{n^2A_k} + \frac{(c-a)^3(3a+c)}{12cI}\right]}S.$$

Professor Heller shows that, for an unsymmetrical portal by his assumptions,

$$S = F\frac{I}{I + I'};$$

that is, if the portal is merely unsymmetrical with respect to the

moments of inertia of the columns. It will be noticed that this simple relation does not hold in case the knees are considered elastic.

Application.s—Assume the following data, to agree with that used in previous examples.

$F = 32{,}000$ lb; $I = I' = 1{,}550$; $c = 125$ in.; $X_c = 36$ in. $= n$; $m = 50.85$ in.; $a = 89$ in. (Fig. 15); $Ak = 4.04$. Then

$$P = P' = 16{,}000 \text{ lb} \left\{ \frac{(\overline{125^3} - 3 \times \overline{89^2} \times 125 + 2 \times \overline{89^3})}{\dfrac{\overline{50{,}85^3}}{\overline{36^2} \times 4.04} + \dfrac{36^3 \times 392}{12 \times 125 \times 1{,}550}} \right\} = 10{,}200 \text{ lb}.$$

By the approximate method already given P was found to equal 9,610 lb. The unit stress in the brace then equals

$$\frac{10{,}200 \times 50.85}{36 \times 4.04} = 3{,}600 \text{ lb per sq. in.},$$

a close agreement with the 3,360 lb per sq. in. obtained by the approximate method. Substituting in the value given for M, gives

$$M = 16{,}000 \times 6.25 - 10{,}200 \times \frac{\overline{36^2}}{250} = 947{,}000 \text{ in. lb}.$$

or a saving in the maximum column bending stress of only 5.3 per cent. by the use of knees.

The point of contraflexure will be located a distance above the foot of the column equal to

$$\frac{947{,}000}{16{,}000} = 59.1 \text{ in}.$$

or the proper value of a to use in the methods given in the earlier part of the chapter would be

$$125 - 59.1 = 65.9 \text{ in.} = 0.527c.$$

Therefore an assumption of $a = c/2$ is a fair one to use in connection with the approximate method for wind loads.

Now, supposing the columns of unequal cross sections the value

of S may be written

$$S = F\left(\frac{I}{I + I'}\right) \times \alpha,$$

where α is a variable coefficient. Assuming all the data of the above problem except that the value of I' is written

$$I' = kI = k \times 1{,}550,$$

where k is a decimal and variable, the curve shown in Fig. 16 has

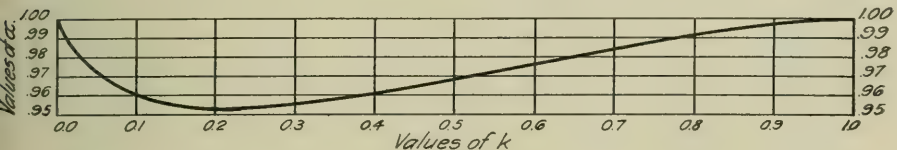


FIG. 16

been drawn to give the values of α for all values of k from zero to unity: it will be noticed that the coefficient does not vary more than 5 per cent. from unity, is always less than unity and may for all practical purposes be considered as constant and equal to 1.

It will now be plain that, for wind stresses, the structure may first be computed as if no knees existed and then the stresses in the columns modified by the use of the approximate methods of this chapter and that for the sizes of the knee braces no arbitrary limiting unit stresses can be assigned, but, rather, the cross section should be assumed in accordance with the engineer's judgment and the column designed to suit.

The economy of the brace can not be a dominant factor unless braces are used both at top and bottom, a design seriously recommended.

CHAPTER XIII.

A DISCUSSION OF WIND PRESSURES ON BUILDINGS.

Wind Velocities.

Wind velocities are measured at all U. S. Weather Bureau Stations by means of the Robinson anemometer. This instrument consists of four hollow hemispherical cups, four inches in diameter, mounted with the open face vertical on the ends of radial horizontal arms connected to a vertical shaft, whose centre is 6.72 inches distant from the centres of the cups. The wind, striking these cups, sets the apparatus revolving about the vertical axis; this motion in turn setting in motion a system of gears which automatically record the amount of the motion on a dial and usually also on an autographically recording apparatus run by clockwork. The gears are so arranged that, after a certain number of revolutions of the axis are made, the dial indicates a change of unity in its reading. Professor Robinson (about 1840) believed, from his experiments, that the wind imparted to these cups a lineal circumferential velocity of the cup centres equal to just one third of the wind velocity and the dial and mechanism was then designed so as to indicate a movement of unity, or one mile, after the cup centres have travelled a distance of one third mile; he believed this ratio was independent of the diameter of the cups, the length of the radial arms, the weight of the instrument, and, above all, the velocity of the wind. Therefore all manufacturers graduated the dials for a uniform movement and they have been made in that manner ever since. In late years it was found that the readings really were dependent on all of these quantities. However, by adopting a standard size and construction for the Weather Bureau Standard and carefully prescribing the care to be taken of all instruments, all errors are practically eliminated save that one depending on the velocity of the wind. To eliminate this latter an extensive series of anemometer tests were made at Washington by the U. S. Weather Bureau and from a study of these results a formula for correcting the anemometer readings was deduced; this formula is $V = 0.509 +$

0.9012 log v, where V is the real velocity of the wind and v is the velocity recorded by the instrument, both in miles per hour. The corrections to indicated velocities by this formula are given in the following table. For intermediate values it will be sufficiently accurate to interpolate.

Indicated velocity = v . .	0	10.0	20.0	30.0	40.0	50.0	60.0	70.0	80.0	90.0
Corrected velocity = V .	0	9.6	17.8	25.7	33.3	40.8	48.0	55.2	62.2	69.2

It is evident that the weight of the instrument reduces the sensitiveness to gusts. However the standard anemometer is designed to be as sensitive as is regarded practicable and, by rating the standard instrument as above, this trouble is practically eliminated.

The wear of the bearings will also cause the instrument to give too small a reading, affecting both steady and gusty wind velocities. However the U. S. Weather Bureau has one such instrument in perfect condition after thrity years service and therefore, with an instrument well taken care of, this item will be negligible.

The anemometer is ordinarily mounted on the end of an eighteen foot vertical support located near the central portion of the roof of the highest building in the vicinity.

WIND PRESSURES.

Observations have been made to determine wind pressures since about 1840 with more or less success, but probably the most trustworthy of all are those made by Professor C. F. Marvin at Mt. Washington. Using the Robinson anemometer he deduces from his experiments the formula

$$p = 0.004 \times \frac{B}{30} \times V^2,$$

where p is the pressure in pounds per square foot, B the barometric pressure in inches of mercury, and V the real or corrected velocity of the wind as given by the velocity formula above.

From this formula the following table of pressures is derived. For all practical purposes it will be sufficiently accurate to interpolate for intermediate values.

Indicated velocity = v .	0	10	20	30	40	50	60	70	80	90
Values of P	0	0.369	1.27	2.64	4.44	6.66	9.22	12.2	15.5	19.2

Professor Marvin calls attention to the fact that for velocities of over 50 or 60 miles an hour this table, while probably the best information obtainable can not be regarded as accurate, because, first, it is very difficult to make observations at high velocities, second, the experiments did not cover velocities above those mentioned (about 60 miles an hour). These experiments were made on surfaces of 4 and 9 square feet.

DISCUSSION.

Effect of Atmospheric Temperature on Wind Pressures.—Mr. A. R. Wolff, in "The Windmill as a Prime Mover," shows that, since the density of the air varies with the temperature and wind is merely air in motion, the pressure of wind varies with the temperature and he further shows this variation to amount to as much as 20 per cent in a temperature range of 100° F.

Effect of Altitude on Wind Pressures.—Since air is lighter in greater altitudes the wind pressure will also be less. Professor Marvin corrects for this in the formula already given. In addition to and quite distinct from this, it is also clearly recognized that the pressure varies as the distance above the general level of the surrounding territory, increasing towards the top of the structure. No very definite determinations of the amount and law of such variations have yet been determined. The variation is probably due to the retarding action of the earth's surface, the effect being similar to that on the flow of streams.

Effect of Size of Exposed Surface.—It is also well recognized that the wind effect on a large surface, per unit of surface, is somewhat less than on small ones such as are used in experimental determinations. Thus, Ketchum, in "Steel Mill Buildings," suggests that the unit pressure on the vertical walls of buildings be considered as 80 per cent of that for small surfaces. The pressure also varies with the shape of the surface, but in building work the surfaces may be so variable and broken that such a refinement is not practicable; most surfaces are, however, plane and rectangular.

Effect of Gusts.—Professor Marvin states that his formula for wind pressure gives the average pressure and that the effect of gusts may vary the pressure 35 per cent either way from the values of the formula (35 to 50 per cent by Langley's experiments), thus making a maximum momentary pressure of 135 per cent of that given by his formula. Professor Langley in his investigations shows that the wind velocity may have five or six maximum and minimum values during a single minute and that while the average variation is about as given by Professor Marvin, the minimum value may reach as low as zero in these variations. Professor Langley says in his conclusions: "The wind is not even an approximately uniform moving mass of air, but consists of a succession of very brief pulsations of varying amplitude, and that, relatively to the mean movement of the wind, these are of varying directions."

Now, if these pulsations should ever agree with the vibrations of the structure subject to pressure, the structure will receive a series of impacts which will, at each successive blow, increase the amount of the vibration until the structure has failed or the periods of vibration disagree. Existing experiments tend to indicate that the period of vibration of a tall building is several seconds (about two to four seconds) and thus the likelihood of such an agreement occurring does not seem impossible. It seems advisable that the increased pressure due to gusts should be considered in designing such a structure as a tall building.

Effect of Suction.—When a large mass of rapidly moving air strikes a fixed mass capable of resisting its direct movement, the central mass of the resisted atmosphere imparts a great portion of its energy of motion in doing work of a more or less evident nature on the obstructing mass and the rest of its energy is spent in deflecting the motion of the outer moving particles so as to pass around the obstruction. This central mass then produces direct pressure on the structure. The outside escaping masses, in leaving the edges and roof, produce a small suction and also on the leeward side of the obstruction, the rapidly moving air will rarefy the space close to the obstruction and create a more or less uniform suction. This has been well demonstrated by the lifting of roofs on the leeward side of houses and barns during severe wind storms.

It is still an open question whether the outward falling of the walls of buildings is due to the sudden decrease of outside atmospheric pressure over that existing inside the structure, or to the suction due to the rapid motion of the wind, as above mentioned. The confusion is due to the fact that the rapidly moving air does not occur independently of the difference in atmospheric pressure.

CONCLUSION.

It must now be evident, from the above, that the pressure of 30 pounds per square foot commonly used in designing is equivalent to an *indicated* velocity of about 130 miles an hour not allowing for gusts, or about 110 miles if gusts are assumed to increase the pressure 35 per cent; these figures are based on a coefficient of 80 per cent for the wall of the building.

It seems to the writer that the customary location of the anemometer may not be quite free from the suction effects mentioned.

It will be noticed that for the high winds that are ordinarily likely to be encountered in experiments on a tall office building (50 miles an hour indicated) the average unit pressures will not be over about 5 pounds per sq. ft. (80 per cent $\times$ 6.66). The probability of a severe storm such as a tornado, with its very narrow path, striking a particular tall building is very small indeed and especially during an investigation of only two months duration, since the Weather Bureau records show only one storm exceeding an indicated velocity of 90 indicated miles an hour in a ten year interval.

CHAPTER XIV.

DESCRIPTION OF AND DATA FOR EXPERIMENTAL BUILDING.

A study of Figs. 17 and 18 will give a comprehensive idea of the position and exposure of the seventeen story office building chosen for the experiments described in the following Chapter. It will

FIG. 17.

be noticed that the building faces south with a twelve story office building abutting on the east and a five story one on the west. As the surface slopes downward rapidly to the west and no obstruc-

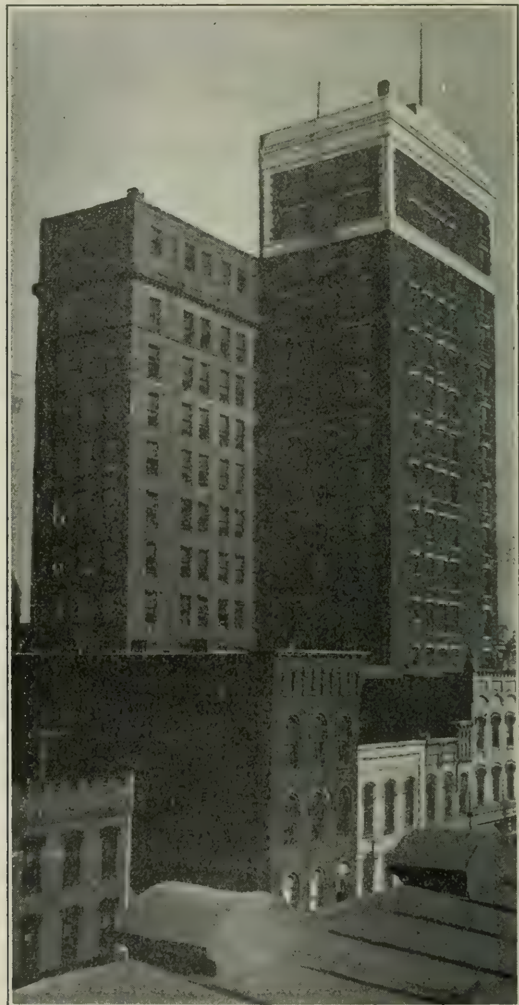
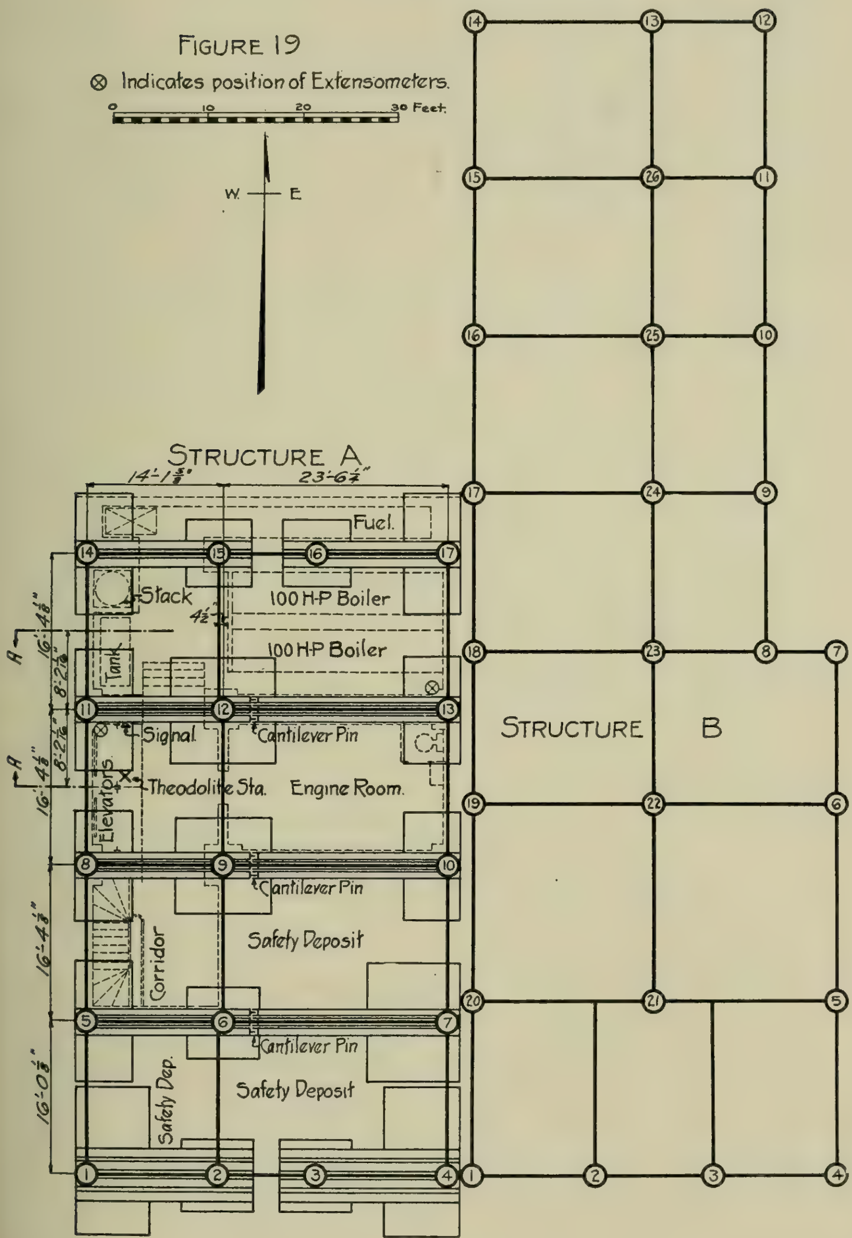


FIG. 18.

tion of any magnitude interferes, the west winds have a most favorable opportunity for displaying the energy embodied in them.

FIGURE 19

⊗ Indicates position of Extensometers.



The fact that the twelve story building abuts against the seventeen story one is, of course, an unfortunate feature, and necessitates the discussion of the characteristics of this building also. In Fig. 19 are shown the general floor plans of the two buildings in their respective positions with the column numbering given for reference throughout the discussion. The seventeen story structure will hereafter be referred to as structure A and the twelve story one as structure B.

Structure B is of the cage construction type with portal bracing, the latter consisting of light I beams (7 in. and 10 in.) with field connections bolted. In other words there is no structural bracing, and rigidity is furnished only by the partitions and inertia of the structure. As shown by Baier in his paper on the St. Louis tornado (*Transactions A. S. C. E.*, Vol. XXXVII, pp. 221, 307), the value of inertia in resisting high wind pressures is not a very dependable quantity, and it seems likely that the *partitions furnish whatever real rigidity this structure possesses.* The building was erected in 1901 and, during erection, was subjected to a fairly severe wind storm. This occurred when the steel frame had been erected, and partitions placed in the two top stories only. The effect of the wind was to distort the portion from the fourth to the tenth story, pushing the tenth story $7\frac{3}{4}$ in. to the east. The two top stories were not distorted, but were kept in a vertical position by the bracing effect of the partitions. The four lower stories were protected by a four story building adjacent. When the structure A was built later, the wedge shaped opening caused by the leaning of structure B at the party wall was filled at both front and rear walls for the sake of appearance.

Fig. 20 shows the type of column used in structure B and the method of splicing same. The following table gives the sections of some of the columns used in this structure and the story heights. All columns are composed of 8 angles, as shown in Fig. 20, and the table gives the size of these angles. Horizontal lines indicate position of column splices. Fig. 21 shows an elevation of the frame of structure A on a section through columns 14, 15, 16, and 17 in the plane of the rear or north wall. Fig. 22 shows a similar section through Columns 11, 12, and 13, two of these columns, 11

Story.	Col. 9.	Col. 24.	Col. 17.	Col. 6.	Col. 22.	Col. 19.	Story Hgt.
Attic	$2\frac{1}{2} \times 2\frac{1}{2} \times \frac{1}{4}$	$2\frac{1}{2} \times 2\frac{1}{2} \times \frac{1}{4}$	$2\frac{1}{2} \times 2\frac{1}{2} \times \frac{1}{4}$	$2\frac{1}{2} \times 2\frac{1}{2} \times \frac{1}{4}$	$2\frac{1}{2} \times 2\frac{1}{2} \times \frac{1}{4}$	$2\frac{1}{2} \times 2\frac{1}{2} \times \frac{1}{4}$	Varies
12							∧
11	$2\frac{1}{2} \times 2\frac{1}{2} \times \frac{1}{4}$		$2\frac{1}{2} \times 2\frac{1}{2} \times \frac{5}{16}$	$2\frac{1}{2} \times 2\frac{1}{2} \times \frac{5}{16}$		$2\frac{1}{2} \times 2\frac{1}{2} \times \frac{5}{16}$	
10		$2\frac{1}{2} \times 2\frac{1}{2} \times \frac{1}{4}$			$3 \times 3 \times \frac{5}{16}$		
9	$3 \times 2\frac{1}{2} \times \frac{5}{16}$		$3 \times 2\frac{1}{2} \times \frac{3}{8}$	$3 \times 2\frac{1}{2} \times \frac{3}{8}$		$3\frac{1}{2} \times 3 \times \frac{5}{16}$	
8		$2\frac{1}{2} \times 2\frac{1}{2} \times \frac{3}{8}$			$3 \times 3 \times \frac{7}{16}$		
7	$3 \times 3 \times \frac{7}{16}$		$3\frac{1}{2} \times 3 \times \frac{3}{8}$	$3 \times 3 \times \frac{7}{16}$		$3\frac{1}{2} \times 3 \times \frac{3}{8}$	All stories 12 ft. 0 in.
6		$3 \times 3 \times \frac{3}{8}$			$3\frac{1}{2} \times 3 \times \frac{1}{2}$		
5	$4 \times 3 \times \frac{7}{16}$		$4 \times 3 \times \frac{7}{16}$	$3\frac{1}{2} \times 3 \times \frac{1}{2}$		$3\frac{1}{2} \times 3 \times \frac{7}{16}$	
4		$3\frac{1}{2} \times 3 \times \frac{7}{16}$			$4\frac{1}{2} \times 3 \times \frac{9}{16}$		
3	$4 \times 3 \times \frac{1}{2}$		$4 \times 3 \times \frac{1}{2}$	$4\frac{1}{2} \times 3 \times \frac{1}{2}$		$3\frac{1}{2} \times 3 \times \frac{1}{2}$	
2		$4\frac{1}{2} \times 3 \times \frac{1}{2}$			$5 \times 3 \times \frac{11}{16}$		∨
1	$4 \times 3 \times \frac{9}{16}$		$5 \times 3 \times \frac{9}{16}$	$4\frac{1}{2} \times 3 \times \frac{9}{16}$		$4 \times 3 \times \frac{1}{2}$	15 ft. — 3 in.
0		$5 \times 3 \times \frac{1}{2}$			$5 \times 3 \times \frac{11}{16}$		11 ft. — 4 in.

and 13, being the ones on which tests were conducted, as described in Chapter XV. Fig. 23 shows the type of column used and method of splicing same. Attention is called to the relative sizes of the columns of structures *A* and *B*. The character of the

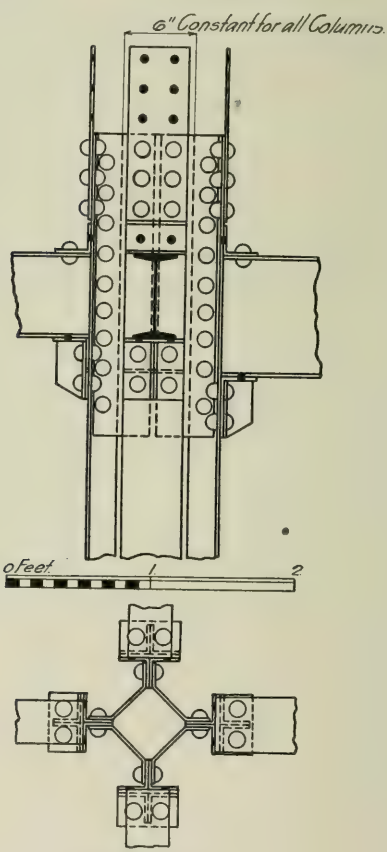


FIGURE 20

footings of structure *A* may be seen by referring to Figs. 19, 21, and 22. The following tables give the sizes and properties of columns 11, 12, and 13 and all story heights and the sections of the four bottom stories of Columns 1, 2, 3, 14, 15, 16, and 17 for comparison.

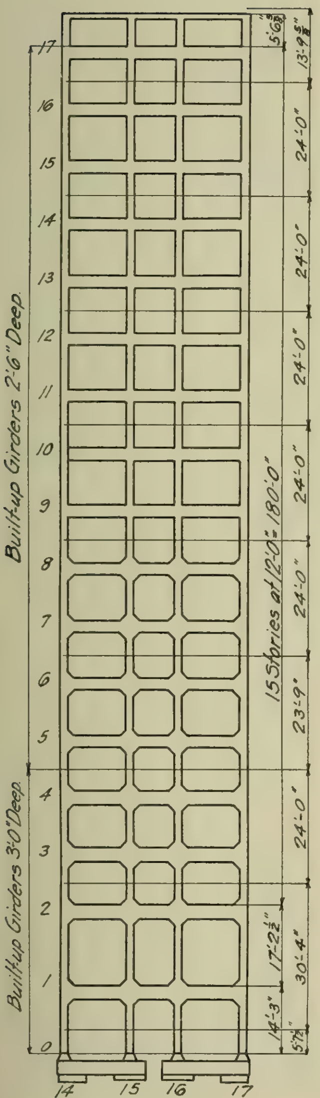


FIGURE 21

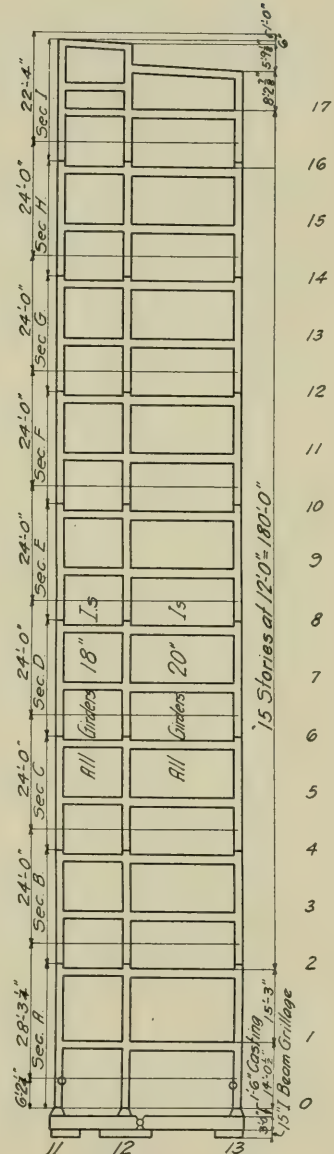


FIGURE 22

Col.	Sec.	Web. (1-Pl.)	4-∠s.	Cov. Pls.	Area.	Length.	I (Web.)	I (4 ∠s). Primary.	I (4 ∠s). Secondary.	I (Cov. Pls.)	Total, I.
11	*A*	$17\frac{1}{2} \times \frac{3}{4}$	$6 \times 4 \times \frac{3}{4}$	2 Pls. $16 \times \frac{7}{16}$	54.88	32 ft. $5\frac{1}{4}$ ins.	335.8	34.8	1,740.0	1,190.0	3,300.6
11	*B*	$17\frac{1}{2} \times \frac{3}{4}$	$6 \times 4 \times \frac{3}{4}$	2 Pls. $16 \times \frac{5}{16}$	50.88	24 0	335.8	34.8	1,740.0	837.2	2,947.8
11	*C*	$17\frac{1}{2} \times \frac{3}{4}$	$6 \times 4 \times \frac{3}{4}$		40.88	23 7	335.8	34.8	1,740.0		2,110.6
11	*D*	$17\frac{1}{2} \times \frac{11}{16}$	$6 \times 4 \times \frac{11}{16}$		37.67	24 0	307.8	32.4	1,616.0		1,956.2
11	*E*	$17\frac{1}{2} \times \frac{5}{8}$	$6 \times 4 \times \frac{5}{8}$		34.38	24 0	279.8	30.0	1,487.5		1,797.3
11	*F*	$17\frac{1}{2} \times \frac{1}{2}$	$6 \times 4 \times \frac{1}{2}$		27.75	24 0	223.8	25.2	1,218.0		1,467.0
11	*G*	$17\frac{1}{2} \times \frac{3}{8}$	$6 \times 4 \times \frac{3}{8}$		21.00	24 0	167.9	19.6	938.0		1,125.5
11	*H*	$17\frac{1}{2} \times \frac{5}{16}$	$5 \times 3\frac{1}{2} \times \frac{5}{16}$		15.71	24 0	140.0	10.8	682.0		832.8
11	*I*	$17\frac{1}{2} \times \frac{5}{16}$	$5 \times 3\frac{1}{2} \times \frac{5}{16}$		15.71	24 0	140.0	10.8	682.0		832.8
12	*A*	$17\frac{1}{2} \times \frac{3}{4}$	$6 \times 4 \times \frac{3}{4}$	2 Pls. $16 \times \frac{7}{16}$	54.88	32 $5\frac{1}{4}$	335.8	34.8	1,740.0	1,190.0	3,300.6
12	*B*	$17\frac{1}{2} \times \frac{3}{4}$	$6 \times 4 \times \frac{3}{4}$	2 Pls. $16 \times \frac{5}{16}$	50.88	24 0	335.8	34.8	1,740.0	837.2	2,947.8
12	*C*	$17\frac{1}{2} \times \frac{3}{4}$	$6 \times 4 \times \frac{3}{4}$	2 Pls. $16 \times \frac{5}{16}$	50.88	23 7	335.8	34.8	1,740.0	837.2	2,947.8
12	*D*	$17\frac{1}{2} \times \frac{3}{4}$	$6 \times 4 \times \frac{3}{4}$		40.88	24 0	335.8	34.8	1,740.0		2,110.6
12	*E*	$17\frac{1}{2} \times \frac{5}{8}$	$6 \times 4 \times \frac{5}{8}$		34.38	24 0	279.8	30.0	1,487.5		1,797.3
12	*F*	$17\frac{1}{2} \times \frac{1}{2}$	$6 \times 4 \times \frac{1}{2}$		27.75	24 0	223.8	25.2	1,218.0		1,467.0
12	*G*	$17\frac{1}{2} \times \frac{7}{16}$	$6 \times 4 \times \frac{7}{16}$		24.42	24 0	195.9	22.4	1,083.5		1,301.8
12	*H*	$17\frac{1}{2} \times \frac{5}{16}$	$5 \times 3\frac{1}{2} \times \frac{3}{8}$		17.67	24 0	140.0	12.8	808.5		961.3
12	*I*	$17\frac{1}{2} \times \frac{5}{16}$	$5 \times 3\frac{1}{2} \times \frac{5}{16}$		15.71	23 $3\frac{1}{4}$	140.0	10.8	682.0		832.8
13	*A*	$17\frac{1}{2} \times \frac{3}{4}$	$6 \times 4 \times \frac{3}{4}$	2 Pls. $16 \times \frac{5}{8}$	60.88	32 $5\frac{1}{4}$	335.8	34.8	1,740.0	1,733.5	3,844.1
13	*B*	$17\frac{1}{2} \times \frac{3}{4}$	$6 \times 4 \times \frac{3}{4}$	2 Pls. $16 \times \frac{7}{16}$	54.88	24 0	335.8	34.8	1,740.0	1,190.0	3,300.6
13	*C*	$17\frac{1}{2} \times \frac{3}{4}$	$6 \times 4 \times \frac{3}{4}$	2 Pls. $16 \times \frac{3}{8}$	52.88	23 7	335.8	34.8	1,740.0	1,013.5	3,124.1
13	*D*	$17\frac{1}{2} \times \frac{3}{4}$	$6 \times 4 \times \frac{3}{4}$	2 Pls. $16 \times \frac{5}{16}$	50.88	24 0	335.8	34.8	1,740.0	837.2	2,947.8
13	*E*	$17\frac{1}{2} \times \frac{3}{4}$	$6 \times 4 \times \frac{3}{4}$		40.88	24 0	335.8	34.8	1,740.0		2,110.6
13	*F*	$17\frac{1}{2} \times \frac{5}{8}$	$6 \times 4 \times \frac{5}{8}$		34.38	24 0	279.8	30.0	1,487.5		1,797.3
13	*G*	$17\frac{1}{2} \times \frac{7}{16}$	$6 \times 4 \times \frac{7}{16}$		24.42	24 0	195.9	22.4	1,083.5		1,301.8
13	*H*	$17\frac{1}{2} \times \frac{5}{16}$	$5 \times 3\frac{1}{2} \times \frac{3}{8}$		17.67	24 0	140.0	12.8	808.5		961.3
13	*I*	$17\frac{1}{2} \times \frac{5}{16}$	$5 \times 3\frac{1}{2} \times \frac{5}{16}$		15.71	17 0	140.0	10.8	682.0		832.8

Note.—All Columns 18 inches b. to b. of ∠s.

Col.	Sec.	Web. (1-Pl.).	4-∠s.	Cov. Pls.	Area.
1	*A*	$17\frac{1}{2} \times \frac{3}{4}$	$6 \times 4 \times \frac{3}{4}$	2 Pls. $16 \times \frac{11}{16}$	62.88
1	*B*	$17\frac{1}{2} \times \frac{3}{4}$	$6 \times 4 \times \frac{3}{4}$	2 Pls. $16 \times \frac{7}{16}$	54.88
2	*A*	$17\frac{1}{2} \times \frac{3}{4}$	$6 \times 4 \times \frac{3}{4}$	2 Pls. $16 \times \frac{3}{4}$	64.88
2	*B*	$17\frac{1}{2} \times \frac{3}{4}$	$6 \times 4 \times \frac{3}{4}$	2 Pls. $16 \times \frac{7}{16}$	54.88
3	*A*	$17\frac{1}{2} \times \frac{3}{4}$	$6 \times 4 \times \frac{3}{4}$	2 Pls. $16 \times \frac{3}{4}$	64.88
3	*B*	$17\frac{1}{2} \times \frac{3}{4}$	$6 \times 4 \times \frac{3}{4}$	2 Pls. $16 \times \frac{7}{16}$	54.88
14	*A*	$17\frac{1}{2} \times \frac{3}{4}$	$6 \times 4 \times \frac{3}{4}$	2 Pls. $16 \times \frac{5}{8}$	60.88
14	*B*	$17\frac{1}{2} \times \frac{3}{4}$	$6 \times 4 \times \frac{3}{4}$	2 Pls. $16 \times \frac{3}{8}$	52.88
15	*A*	$17\frac{1}{2} \times \frac{3}{4}$	$6 \times 4 \times \frac{3}{4}$	2 Pls. $16 \times \frac{3}{8}$	52.88
15	*B*	$17\frac{1}{2} \times \frac{3}{4}$	$6 \times 4 \times \frac{3}{4}$	2 Pls. $16 \times \frac{5}{16}$	50.88
16	*A*	$17\frac{1}{2} \times \frac{3}{4}$	$6 \times 4 \times \frac{3}{4}$	2 Pls. $16 \times \frac{3}{8}$	52.88
16	*B*	$17\frac{1}{2} \times \frac{3}{4}$	$6 \times 4 \times \frac{3}{4}$	2 Pls. $16 \times \frac{5}{16}$	50.88
17	*A*	$17\frac{1}{2} \times \frac{3}{4}$	$6 \times 4 \times \frac{3}{4}$	2 Pls. $16 \times \frac{1}{2}$	56.88
17	*B*	$17\frac{1}{2} \times \frac{3}{4}$	$6 \times 4 \times \frac{3}{4}$	2 Pls. $16 \times \frac{3}{8}$	52.88

CHAPTER XV.

DESCRIPTION OF AND RESULTS FROM EXPERIMENTS.

The experiments conducted on structure *A* of the previous chapter are in some respects limited. These experiments were undertaken with the view of determining, if possible with the limited resources and working conditions available, the following features: first, the manner of variation and amount of the unit stresses in the basement columns of a high portal braced structure under the action of wind pressures; second, the period of vibration of such a structure under variable wind velocities; and third, the total deflection of the structure, at the top, under wind pressures.

The following are the features which either limit or mar the value of these experiments.

First. The only exterior columns (11 and 13) to which access could be had can not be said to be connected rigidly to the floor girders, since these girders are merely 18 in. and 20 in. I beams with the customary connections (see Fig. 22 and 23). No knees were used and the connections are capable of transferring only small bending moments. The value of these connections, in bending, will be given a little later. As will be seen from Fig. 21 the bracing in the planes of the front and rear walls is very much more rigid, although the form of connection still subjects the rivets to direct tension under the flexure due to wind pressure (as well as all other causes). These sections may however be said to be really portal braced, and, in addition, have the stiffening effect of the walls of the building. It must be realized that if the girders could not take care of *any* bending at the connections and there were no other factor to resist distortion, then the frame must simply close up on itself under lateral forces, as shown in Fig. 24. Thus, if the connections to Columns 11, 12, and 13 were purely of this type, then evidently the sections in the front and rear walls *must* take care of all lateral forces, these forces being transferred to them at each story through the floors, which act as deep, stiff girders, as was mentioned

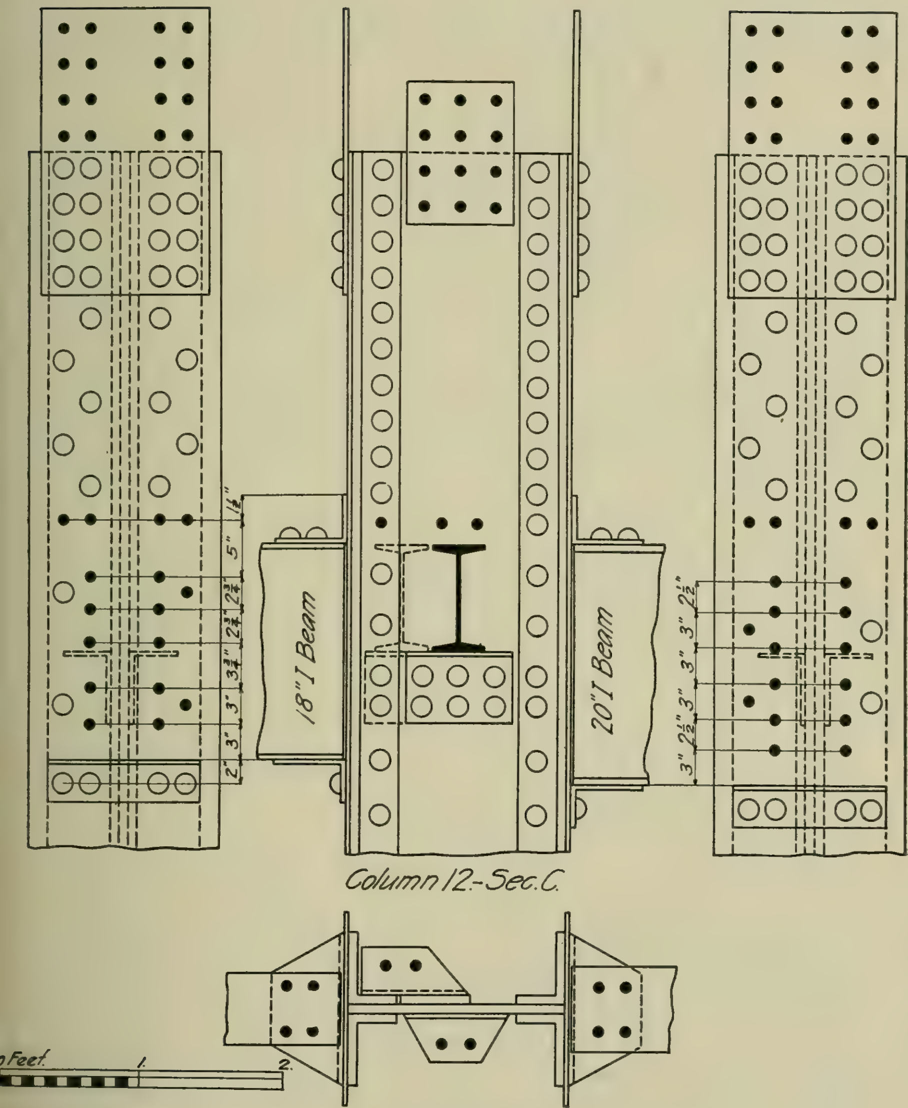


FIGURE 23.

in Chapter II. Thus it is regretted that the stresses in the columns in either front or rear could not also have been measured.

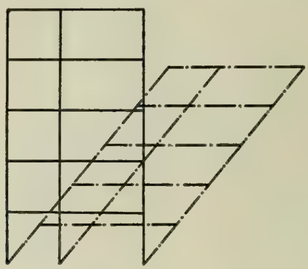


FIG. 24.

Second. Extensometers could only be attached to one corner of the columns and thus it is impossible to determine just what part of the measured stress is due to flexure and what part is axial stress.

Third. It would have been highly desirable to measure the stresses in the columns at say every third or fourth story and to obtain the measurements as nearly simultaneously as practicable.

Fourth. The element of resistance afforded by structure B to the west winds (the only winds whose effects are considered in this investigation) is a very uncertain one. It may be as low as nothing for ordinary wind velocities but for very violent storms it would undoubtedly amount to something.

Fifth. As will be shown later, the largest variation of unit stress to be expected under the most reasonable assumptions for the maximum winds obtained requires the most delicate measurement and careful corrections for variations of Column temperatures and instrument variations caused by variation of temperature and relative humidity.

Sixth. The observations for deflection and vibration of the building were made with a theodolite in the elevator shaft and elevator service could not be interrupted (an exception to this was made one evening).

The small space allowed for placing signals and lights and resultant poor illumination and the risk of life and instruments in the shaft, under a moving elevator run by irresponsible youths, together

with the necessity of the writer to make all preparations and observations without assistance, combined to make these observations of short duration, infrequent and of a much less elaborate nature than was intended.

DESCRIPTION AND USE OF APPARATUS.

Vibration and Deflection Experiments.—A theodolite was placed in the elevator shaft at the point marked X in Fig. 19, this point being a tack set in the concrete floor of the bottom of the shaft. A signal, as shown in Fig. 25, *a*, was securely wedged in between the elevator guide and the wall at the middle of the sixteenth story so as to be just visible from the foot of the shaft when the elevator was clear at the top, *i. e.*, at the seventeenth floor. The divisions on this signal were one half inch. The signal shown in Fig. 25, *b*

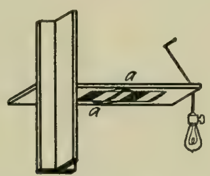


FIG. 25-a

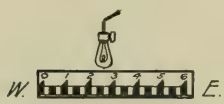


FIG. 25-b

was nailed to the wall of the shaft at a point about two feet above the first floor level. It could not be placed any lower, as the minimum focal distance for the telescope of the theodolite was about ten feet. The graduations for this signal were one quarter inch and read from west to east as shown.

The theodolite was equipped with a prismatic eyepiece. When set up in the shaft the plate bubbles were carefully levelled, then, turning the instrument into the plane of the signals, the striding level was placed in position, always with its adjusting end to the west, and the level carefully brought to the center with the instru-

ment in this position. Removing the striding level and focusing on the light at the signal of Fig. 25, *a*, the cross hair was set on the line "*aa*" of the signal, an average of the vibrations of "*aa*" back and forth being judged by the equal widths of white and black covered by the cross hair as its apparent motion swung back and forth. After securing this setting the telescope was plunged to the signal of Fig. 25, *b*, and a reading recorded as "direct reading." The instrument was then reversed and, without reapplying the striding level, the above operations were repeated and the reading on the signal of Fig. 25, *b*, was recorded as "reversed reading." The striding level was then applied to test for any settlement that might affect the readings.

In the observations for building vibration the lower signal was not used, but vibrations were estimated by eye on the half inch scale divisions of the signal of Fig. 25, *a*.

Experiments for the Determination of Column Stresses.—As has already been mentioned these experiments were made on the basement sections of columns 11 and 13. The Boyd-Morris extensometer, which has been so successfully used at the Ohio State University for some years past, was used to measure the change in length of the columns. This instrument is shown (not to scale) in Fig. 26 and in position on Column 13 in the cut, Fig. 27. Center-punch holes, about $\frac{1}{32}$ in. deep, were made in the steel columns for the reception of the hardened points shown on the brackets at *A* and *B*; these brackets were then placed in position and 8 in. malleable iron clamps used to hold them securely to the column. Center punch marks were used as an extra precaution against slipping of the brackets. The nut at *C* was then adjusted until the piston *CD* came to a bearing on the plunger *E*, did not stand out of the cup *F*, and yet left sufficient allowance for free variation in the height of the bottom of the piston. The set screws at *D* were then tightened and the spring clip *G* adjusted so as to hold the bottom of the piston against the inner wall of the cup *F*.

The set screws *H* were then adjusted so as to take out all play in the bearings, which are shown in Fig. 26, *a*, to a larger scale. The micrometer *I* was then adjusted so as to be in a vertical plane with the black pinhead *J* centered over the micrometer screw and

proper allowance was made for the expected vertical movement of the pinhead J.

It will be seen then, that if there is any change in the length of the section A–B of the column, the bracket at A will move relatively to that at B; the amount of this movement will be the amount of the relative variation in height of the bottom of the piston CD, except as modified for the effects of temperature, etc. Now, if the plunger E is, at each observation, pushed into contact with the bottom of the piston CD, and a light rubber band placed around the lever as shown in the Fig. 26, to keep the knife edge of the lever HJ constantly in contact with the bottom of the plunger, then the vertical variation of the height of the black spherical head of the pin J will be 50 times the corresponding change in length of the column. Thus, by reading the micrometer I to the delicate tangential contact of the pinhead J with its reflection in the polished top of the micrometer screw, a series of readings may be obtained, indicating the range of stress in the column. A thermometer K was clamped to the column in the position shown and at its base a wooden cup L, with an open face next the column surface, was pasted and clamped to the column around the mercurial bowl of the thermometer and this cup was then filled with mercury so as to give as correct a value of column temperature variation for the height AB as possible. The wooden rod CD will be subjected to temperature correction as will also the steel column and the temperature variation for it is taken the same as indicated by the thermometer for the column. The coefficient of expansion for the wooden rod will be about one third of that for steel, according to Trautwine, and therefore, for a variation of column temperature of 1° F. the coefficient of expansion used in correcting the readings of the micrometer I for temperature variation will be taken as $\frac{2}{3} \times 0.0000067$.

It is realized that the varying relative humidity might affect the length of the wooden rod CD and the writer has been unable to find records of tests for the variation of length due to such a cause; the only related data found was a series of saturation tests (water soaked for 37 days) by De Volson Wood. These gave an elongation for saturation of 0.00065 of the length, for pine. Wood will absorb as high as 50 per cent. of its dry weight of water and from 8 to 16

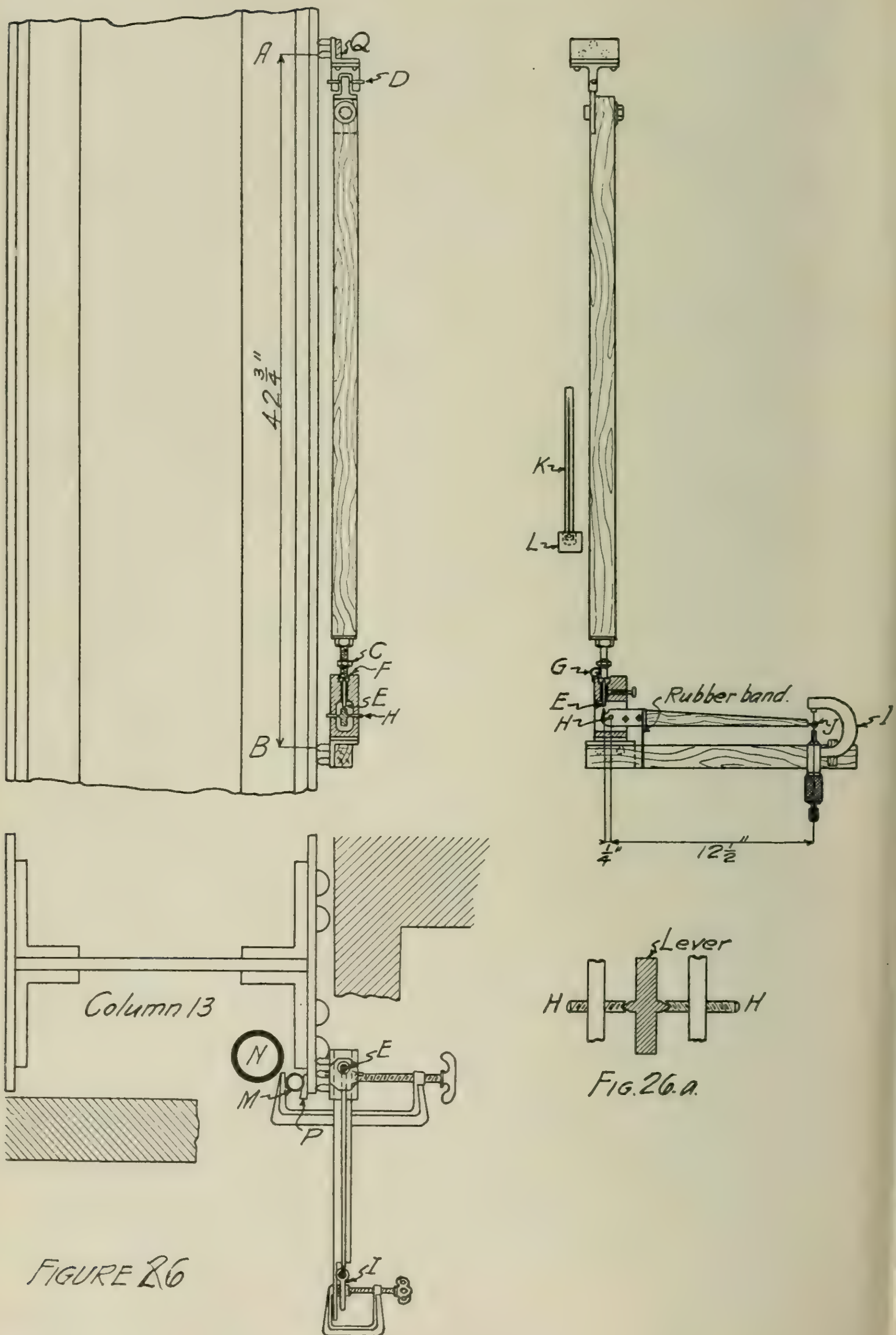


FIG. 26. a.

FIGURE 26

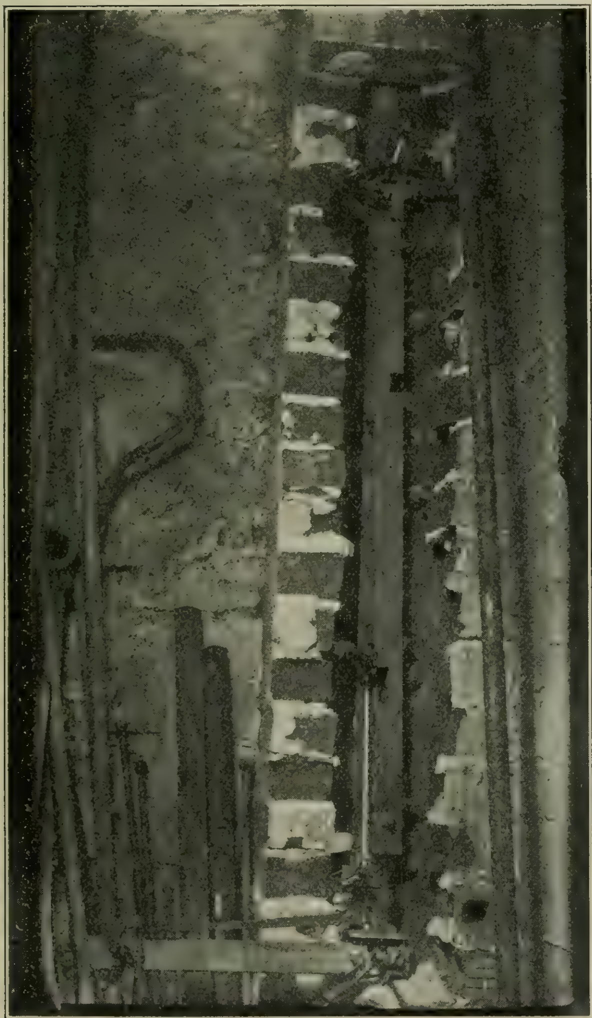


FIG. 27.

per cent. from the atmosphere. The conditions of the outside air, however, are far different from those in the basement of this structure, in which are no windows or doors communicating directly with the outside air. In addition, natural gas is burned under the boilers nearby the columns tested and a high and nearly constant temperature is maintained in this part of the building. It is considered in the absence of tests that the small changes in humidity will cause no appreciable change in length of the rod *CD*.

It has been suggested by Professor Boyd that an invar rod be used for *CD* in place of the wooden one now used; this would eliminate both the temperature correction of the extensometer and all uncertainty due to humidity.

In the experiments on Column 13 difficulty was encountered in satisfactorily clamping the brackets to the column. This was due to the presence of a one inch wrought iron water pipe *M* and a three inch cast iron water pipe *N*, as shown in Fig. 26. Wooden wedges *P*

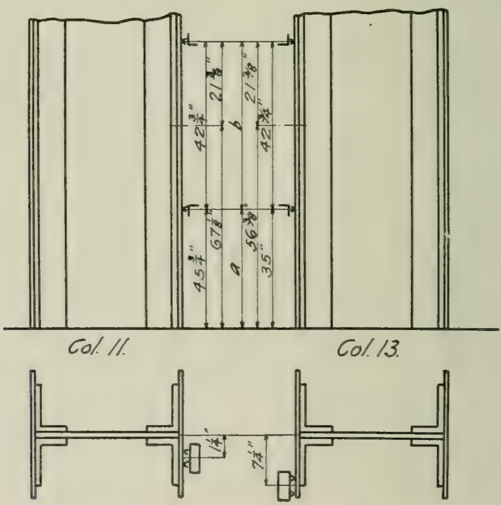


FIG. 28-a FIG 28-b

were driven in between the pipe *M* and the column and the clamps then extended from the brackets around the pipe *M*, a wooden block *Q* being placed over the bracket at *A* as a further precaution. The pipe *M* was always cold.

Connections were made directly to Column 11 but no mercury contact was provided for the thermometer in that case.

The position of extensometer attachments to Columns 11 and 13 is shown in Figs. 22, 28, *a*, and 28, *b*, respectively.

Weather Bureau Records.—The station anemometer and weather vane for this vicinity are located on the rear of the top of structure *A* (see Figs. 17 and 18). On the first of the month visits were made to the Weather Bureau Office and the indicated wind velocities and wind directions were recorded for the time of each micrometer and theodolite reading taken. Also, the thermograph records were carefully traced on transparent paper, later to be reconstructed on another scale, using vertical ordinates.

ANTICIPATED AND MEASURED RESULTS.

Deflection and Vibration—Anticipated Results.—It has been shown in Chapter X that the deflections of a structure as computed by the methods of Chapter II are very much less than when computed by the methods of Chapter III.

As has also been shown, the method of Chapter III is very laborious and therefore, in calculating anticipated deflections the methods of Chapter II will be used.

Structures are usually designed for a uniform wind pressure of 30 pounds per square foot of surface and the deflection of the top of the building will be computed for this pressure. It will also be computed for the maximum wind pressure experienced during these investigations. This was for an indicated northwest wind velocity of 44 miles per hour, which interpolating in the table of Chapter 13 is equivalent to an average pressure of 5.33 pounds per square foot. Resolving into north and west components gives a west wind of $0.707 \times 5.33 = 3.77$ pounds per sq. ft. Allowing an increase of 35 per cent for gusts and using a coefficient of 80 per cent for the wall surface, there results a pressure of $3.77 \times 1.35 \times 0.80 = 4.06$ pounds per square foot. The total deflection will then be calculated for pressures of 30 and 4.06 pounds per square foot.

Referring now to Fig. 22 the heights of the stories and the depths of the girders will be found, and Fig. 19 gives the widths of the bays and the spacing of the columns.

First it will be considered that the section through columns 11, 12, and 13 is thoroughly portal braced. Then the wind on a section 16 ft. $4\frac{1}{8}$ in. wide will be assumed to be transferred to these columns. The values of the deflections for 30 pounds per sq. ft. are then as follows:

Story.	C	F	ΣF	S''	δ''
16	126	10,903	10,903	3,635	727,500
15	126	5,884	16,787	5,075	1,016,000
14	126	5,884	22,671	6,855	1,372,000
13	126	5,884	28,555	8,615	1,276,000
12	126	5,884	34,439	10,390	1,539,000
11	126	5,884	40,323	12,500	1,420,000
10	126	5,884	46,207	14,320	1,628,000
9	126	5,884	52,091	16,400	1,521,000
8	126	5,884	57,975	18,260	1,694,000
7	126	5,884	63,859	17,800	1,518,000
6	126	5,884	69,743	19,440	1,659,000
5	126	5,884	75,627	19,500	1,539,000
4	126	5,884	81,511	21,020	1,660,000
3	126	5,884	87,395	28,010	1,583,000
2	126	5,884	93,279	29,900	1,690,000
1	165	6,683	99,962	31,550	3,580,000
0	150.5	7,180	107,142	33,800	2,915,000

$\Sigma = 28{,}337{,}000$ in.

Thus the total deflection at the seventeenth floor for a pressure of 30 pounds per square foot would be only

$$\frac{28{,}337{,}000}{28{,}000{,}000} = 1.012 \text{ in.}$$

Then, for a pressure of only 4.06 pounds per sq. ft. the deflection would be

$$\frac{4.06}{30} \times 1.012 = 0.136 \text{ in.}$$

Now, if the same ratio (1 : 3.08) between the results of the methods of Chapters II and III respectively, as was found in Chapter X be considered to exist here, the value of the above deflections would be 3.12 in. and 0.420 in. respectively.

Again, suppose that the sections in the north and south walls of the structure are the only sections resisting wind pressure and that the resistance of the walls be neglected. As was noticed in Chapter XIV the section areas of the columns 14, 15, 16, and 17 are about

the same as those of columns 11, 12, and 13; let them, for these calculations, be assumed all equal and the same as column 11. Remembering that S^{14} will then equal $\Sigma F/4$, the deflections will be as follows:

Story.	C	F	ΣF	S^{14}	δ^{14}
16	114	13,525	13,525	3,381	502,000
15	114	11,768	25,293	6,323	937,500
14	114	11,768	37,061	9,265	1,374,000
13	114	11,768	48,829	12,207	1,340,000
12	114	11,768	60,597	15,149	1,664,000
11	114	11,768	72,365	18,091	1,524,000
10	114	11,768	84,133	21,033	1,772,000
9	114	11,768	95,901	23,975	1,650,000
8	114	11,768	107,669	26,917	1,850,000
7	88.5	11,768	119,437	29,859	880,000
6	88.5	11,768	131,205	32,801	967,000
5	88.5	11,768	142,937	35,743	976,000
4	88.5	11,515	154,488	38,622	1,054,000
3	82.5	11,768	166,256	41,564	657,000
2	82.5	11,768	178,024	44,506	705,000
1	145	14,305	192,329	48,082	3,700,000
0	135	15,420	207,749	51,937	3,225,000

$\Sigma = 24,777,000$ in.

Thus the total deflection at the seventeenth floor for a pressure of 30 pounds per square foot would be only

$$\frac{24,777,000}{28,000,000} = 0.885 \text{ in.}$$

Then, for a pressure of only 4.06 pounds per sq. ft. the deflection would be

$$\frac{4.06}{30} \times 0.885 = 0.120 \text{ in.}$$

Now, under the assumption that the floors carry all the wind pressure to the ends of the building it will be seen from this table that the total wind load carried by any one floor is only about 24,000 pounds, and as the floors form very deep wind girders the deflection of the floors at the section through columns 11, 12, and 13 will certainly be very small. Suppose it to be negligible; then from the above figures it will be seen that, in this particular design, practically the same deflection at the section through columns 11, 12, and 13 is obtained whether this section is assumed as strictly portal braced or with no bracing whatever.

The only records of tests on tall buildings that the writer has been able to find are those on the Monadnock and Pontiac Buildings in Chicago, the first named building being a seventeen story structure which might be considered as really two structures, one of veneer cage construction and the other of skeleton construction with solid brick walls six feet thick at the sidewalk. The Pontiac building is a fourteen story one of the skeleton construction type. The maximum vibrations were observed on the Monadnock building and ranged from $\frac{1}{4}$ in. to $\frac{1}{2}$ in., the larger values being for the portion of the veneer construction type. The wind had an indicated velocity of 80 miles an hour and came from the northwest and the exposed portion of the building considered faced west. This wind is equivalent to

$$15.5 \times 0.707 \times 1.35 \times 0.80 = 11.80 \text{ pounds per square foot.}$$

It will be noticed that such a pressure on the seventeen story building considered in this Chapter would cause a maximum deflection of

$$\frac{11.80}{30} \times 1.012 = 0.394 \text{ in.}$$

under the most favorable condition for deflection, *i. e.*, that section 11–12–13 is rigidly braced.

There is no great discrepancy between this vibration of $2 \times 0.39 = 0.78$ in. and the $\frac{1}{2}$ in. observed vibration and when it is remembered that the sizes of the columns, their unsupported height and the number of columns in a cross section are the factors affecting the amount of the deflections and that when the structure is calculated as an entirely elastic one the deflections would not likely exceed $3.08 \times 0.394 = 1.21$ in., it can only be said that these actual observations merely furnish a reasonable estimate of the value of walls and partitions in resisting wind pressure and do not seem to furnish such a disagreement as Freitag in "Architectural Engineering" points out.

Although the writer has no data on the frame of the Monadnock block, he believes his estimates above to be large, as the Monadnock block is a wider structure than that considered in this chapter.

Date.	Time	Ind. V.	Direct.	Dir. Read.	Rev. Read.	Time of Vib.	Amt. of Vib.	Act. V.	Resolved V.	Remarks.
2–28	3:10 P.M.	9	N.W.	+0.09		Not noticeable	Not noticeable	8.6	6.1	On west end of old signal.
3–2	9:35 A.M.	20	W.	−0.06		Not noticeable	Not noticeable	17.8	17.8	On west end of old signal.
3–4	8:45 A.M.	16	N.N.W.	+6.46		Not noticeable	Not noticeable	14.4	5.5	On east end of old signal.
3–4	8:50 A.M.	16	N.N.W.		+6.92	Not noticeable	Not noticeable	14.4	5.5	On east end of old signal.
3–8	3:45 P.M.	5.5	S.	+2.06		Not noticeable	Not noticeable	5.5	0	Remaining obs. on signal of Fig. 25, *a*.
3–8	3:50 P.M.	5.5	S.		+2.44	Not noticeable	Not noticeable	5.5	0	
3–15	10:15 A.M.	36	N.W.	+2.12		Ab't 8 sec.	Ab't $\frac{3}{8}$ in.	30.2	21.3	
3–15	10:20 A.M.	38	N.W.		+2.31	Ab't 8 sec.	Ab't $\frac{3}{8}$ in.	31.6	22.4	
3–15	10:30 A.M.	44	N.W.		+2.46	Ab't 4 sec.	Ab't $\frac{1}{2}$ in.	36.3	25.6	
3–15	3:50 P.M.	41	N.W.	+1.81				34.0	24.0	
3–15	3:54 P.M.	41	N.W.		+2.38	From	From	34.0	24.0	
3–15	4:05 P.M.	34	N.W.		+2.12	8 to 12 sec.	$\frac{1}{4}$ to $\frac{3}{8}$ in.	28.7	20.3	
3–15	4:10 P.M.	27	N.W.	+1.62				23.3	16.5	
3–27	9:04 P.M.	32	W.	+1.38				27.2	27.2	At 8–30 before ready for observing
3–27	9:12 P.M.	37	N.W.		+1.88	About 8 sec.	Avge. $\frac{1}{8}$ in.	30.7	21.7	noted vibration of about $\frac{1}{2}$ in. Ind.
3–27	9:18 P.M.	35	N.W.	+1.31			Max. $\frac{1}{4}$ in.	29.6	20.9	V = 24 Mi. west.
3–27	9:31 P.M.	35	W.		+1.75			29.6	29.6	
3–31	4:20 P.M.	5	W.	+1.67		Not noticeable	Not noticeable	5.0	5.0	
4–5	7:55 A.M.	22	S.W.	+1.71		Not noticeable	Not noticeable	19.4	13.7	

A tall building is such a composite structure that the time of vibration can not be closely estimated and no attempt is here made to do so. The time of vibration given for the Chicago experiments was two seconds.

Results as Observed on Structure A.—The records of observations for deflection and vibration, as made by the writer are as given in the table on page 205.

From the above table it will be seen that the largest indicated velocity during the observations was 44 miles per hour, equivalent to a pressure of 4.06 pounds per square foot normal to the west wall. The largest observed vibration was of a momentary nature and not greater than $\frac{1}{2}$ in. The times of vibration seem quite variable and in fact there was evidence that any one vibration as observed was itself made up of a number of much smaller and more rapid vibrations. The times of vibration seem quite variable and do not seem closely related to the indicated velocities. It is known that the time of vibration should theoretically vary about as the square root of the pressure or almost directly as the velocity and about as the three halves power of the height of the structure for a comparison of different structures. This is on the assumption that the structure acts like a beam, an assumption which has been shown to be far from correct. As noted in the remarks column of the above table the first four readings of signal Fig. 25, *b*, were from sights on an old signal in place of that of Fig. 25, *a*, and are not related to the following readings. The readings on the signal of Fig. 25, *b*, have a variation of $\frac{3}{4}$ in., both in the direct and reversed readings. The writer can only account for this by assuming that the effects of temperature, described later, caused the building to lean; this seems especially probable since the results indicate a leaning to the west on March 27 of $\frac{3}{4}$ in. from the readings of March 15 under almost identical conditions of the wind. Striding level tests showed only very small settlements of the theodolite and could not account for more than $\frac{1}{16}$ in. variation, as tested.

Assuming a maximum vibration of $\frac{1}{2}$ in., as found above, for a pressure of 4.06 pounds per square foot, this vibration will be closely twice the deflection from the normal position, since the vibrations pass back and forth through this position; therefore the observed

deflection for the top of the structure under a pressure of 4.06 pounds per sq. ft. may be taken as 0.25 in. By the methods of Chapter II it was found that this deflection would be 0.14 in. and by Chapter III about 0.42 in. These figures take into account the effect of gusts and indicate that the walls and partitions reduce the deflections about 40 per cent. In other words, the walls and partitions in this structure seem to be secondary and not primary agencies in resisting distortion due to wind. This is certainly a highly desirable feature in a tall building. The dependence on the walls and partitions is probably even less than given here, for it is believed that the ratio 1 : 3.08 from Chapter X, will be found to be too small for higher structures than the five story one, of only two columns to a cross section, to which it refers.

COLUMN STRESSES—ANTICIPATED RESULTS.

The unit stresses at the position of the extensometers on columns 11 and 13 will now be computed by the method of Chapter II for pressures of 30 and 4.06 pounds per square foot.

For 30 pounds, the unit column stresses at the points of contraflexure (half the unsupported height from the casting) are as in the following table.

X	Y	h^{11}	h^{12}	h^{13}	s	s^{11}
+140,400,000	0	+215.8	+46.1	+236.1	+23.14	−4,990
X	Y	s^{12}	s^{13}	V^{11}	V^{12}	V^{13}
+140,400,000	0	−1,066	+5,465	−274,000	−58,500	+332,500

The extensometer on column 11 was placed 7.13 in. and that on column 13, 17.87 in. below the points of contraflexure and on the inner extreme fibres of the columns. If these distances are designated as "z," then for both of these columns the extreme fibre unit stresses will be less than those given in the above table by the amount $Sz \cdot v/I$. The total wind shear on the section is 107,142 pounds, as already given. Then

$$S^{11} = 33{,}800 \text{ lb}, \quad S^{12} = 33{,}800 \text{ lb}, \quad \text{and} \quad S^{13} = 39{,}540 \text{ lb}.$$

The extreme fibre stress for column 11 at the extensometer will be

$$-4{,}990+\frac{33{,}800\times 7.13\times 9.44}{3{,}300.6}=-4{,}990+689=-4{,}201 \text{ lb per sq. in.}$$

For column 13 the stress would be

$$+5{,}465-\frac{39{,}540\times 17.87\times 9.62}{3{,}844.1}=+5{,}465-1{,}767$$
$$=+3{,}698 \text{ lb per sq. in.}$$

Now for a maximum pressure of 4.06 pounds per square foot these quantities become

$$\frac{4.06}{30}\times -4{,}201=-568 \text{ lb per sq. in.}$$

and

$$\frac{4.06}{30}\times 3{,}698=+500 \text{ lb per sq. in.}$$

respectively.

It is now interesting to note a few of the relations concerning the interpretation of the micrometer readings.

The smallest reading of the micrometer is 0.001 in.

The extensometer magnifies changes in length 50 times.

One division of the micrometer (0.001 in.) is equivalent to

$$\frac{0.001\times 28{,}000{,}000}{50\times 42.75}=13.10 \text{ lb per sq. in.}$$

of unit stress in the column.

One degree change in temperature is equivalent to

$$\frac{0.0000067\times 42.75\times 50}{0.001}=14.4$$

divisions of the micrometer, or two-thirds of this, equal to 9.57 divisions when the simultaneous expansion of the wooden piston *CD* is allowed for.

Also, one degree change of temperature is equivalent to $9.57\times 13.10=125.3$ pounds per sq. in. of change of unit stress in the column.

The maximum number of divisions of the micrometer to be expected to be recorded under wind pressure would then be only

$$\frac{568}{13.10} = 43.4$$

(twice this, allowing for vibration back and forth).

An error of about 8° F. in column temperature or possibly a small change in relative humidity would entirely vitiate these results.

It was shown by the method of Chapter III that the points of contraflexure fall considerably above the mid height. Suppose they occur at the three quarter point; then the stresses at the extensometers on columns 11 and 13 become, for 30 pounds per sq. ft.

$$-4{,}990 + 33{,}800 \times \frac{44.25 \times 9.44}{3{,}300.6} = -700 \text{ lb per sq. in.}$$

and

$$+5{,}465 - \frac{39{,}540 \times 55.00 \times 9.62}{3{,}844.1} = +15 \text{ lb per sq. in.}$$

respectively. For a pressure of 4.06 pounds these stresses are only -95 and $+2$ lb per sq. in. respectively. In this case the stress would hardly be noticeable in column 11 and certainly not in evidence in column 13.

The rigidity of the connections of the 18 in. I beam floor girders to column 11 will now be investigated. The shear in the column in the basement story, for a 30 pound pressure, is 33,800 lb and in the first story 31,550 lb, as given in previous table. Thus the connection must be able to resist a bending moment of

$$31{,}550 \times 91.5 + 33{,}800 \times 84.25 = 5{,}735{,}000 \text{ in. lb.}$$

For a pressure of 4.06 pounds the connection must resist a moment of

$$\frac{4.06}{30} \times 5{,}735{,}000 = 775{,}000 \text{ in. lb.}$$

Referring now to Fig. 23 the rivets and spacing used for this connection will be found. The strength of the connection evidently

depends on the value of a rivet in direct tension and experience has shown that no definite distinction can be made between shop and field driven rivets in this respect. Consider that the wind tends to bend the column around the toe of the upper connection angle. Then, if s represents the value of the rivet in the vertical leg of the lower connection angles and the value of the other rivets is assumed proportional to the distance from the toe of the top angle, the moment of resistance of the connection will be

$$\frac{s}{23.75}[4 \times \overline{1.5}^2 + 2 \times \overline{6.5}^2 + 2 \times \overline{9.25}^2 + 2 \times \overline{12.00}^2 + 2^2 \times \overline{15.75}^2 + 2 \times \overline{18.75}^2 + 4 \times \overline{23.75}^2] = 169s.$$

The turning moment around the toe of the top angle will be a little greater than that previously deduced for the neutral axis, but the difference is not great and it is close enough to say that

$$169s = 775{,}000$$

or

$$s = 4{,}580 \text{ lb},$$

this being then the maximum stress on a rivet. All rivets are $\frac{3}{4}$ in. It is well known that a rivet may be worth as low as zero for this type of stress or may stand a much higher stress. It is to be realized that the resultant stress on these rivets will be higher than 4,580 lb because of the vertical shearing stress which they receive. Another item to consider is that such a stress as this on the rivet will cause the joint to give sufficiently to destroy to a great extent the fixed condition assumed to start with.

These figures all indicate that the sections in the north and south walls furnish the most of the resistance to wind; especially must this be true for much higher pressures than 4.06 pounds per square foot.

The following table gives the results obtained in these experiments.

For Column 11.											
Date.	Time.	Col. T.	Microm.	Ind. V.	Direction.	Actual V.	Microm. Corr. to 66°.		Value in Lbs. per Sq. In.	W. Comp. of V.	Remarks.
3– 1	8:10	64.6°	0.558	9	W.	See Col. 13 as the times of obs. are about the same.	0.571	Subtract 0.200 from all readings before converting into stress.	4,860	See Col. 13.	
1	4:40	66.2	0.546	18.5	W.S.W.		0.544		4,510		
2	8:35	64.0	0.515	22	W.		0.534		4,375		
2	4:00	64.7	0.507	25	W.		0.519		4,180		
3	3:05	66.0	0.477	9	W.		0.477		3,630		
4	8:10	67.8	0.466	13	N.W.		0.449		3,260		
6	7:50	68.0	0.496	18	N.		0.477		3,628		
6	4:10	68.7	*0.521*	14	N.E.		0.495		3,863		Reset microm. Reads 0.393 after.
7	7:20	67.9	0.458	11	S.E.		0.568		4,825		
7	4:15	69.0	0.443	15	N.E.		0.542		4,480		
8	7:35	67.7	0.426	8.5	N.N.E.		0.538		4,427		
8	4:20	69.1	0.378	5	S.S.E.		0.476		3,617		
9	8:00	69.5	0.320	10	S.S.E.		0.414		2,804		
9	3:50	70.9	0.283	12	S.		0.364		2,147		
10	7:30	71.5	0.212	5	W.		0.287		1,140		
10	3:56	71.7	0.203	5	W.		0.276		995		Tested pivots. Assume readings identical after reset.
10	4:40	72.5	0.324	5	W.		0.276		995		
11	8:19	69.4	*0.446*	20	E.N.E.		0.427		2,973		Reset microm. Reads 0.394 after.
13	7:35	68.7	0.305	9	W.		0.345		1,900		
13	4:11	71.7	0.392	16	E.N.E.		0.403		2,660		
14	7:40	70.0	0.468	4	E.		0.496		3,877		
14	3:55	69.9	0.422	5	S.W.		0.451		3,286		
15	7:36	67.8	0.371	9	W.		0.420		2,880		
15	11:00	68.0	0.351	40	N.W.		0.398		2,595		
15	3:10	67.7	0.363	40	N.W.		0.413		2,790		
16	8:00	63.3	0.413	15	W.		0.505		4,000		
16	3:30	61.6	0.430	9	W.		0.538		4,430		
17	4:09	65.8	0.440	17	S.		0.508		4,035		

For Column 13.

Date.	Time.	Col. T.	Microm.	Ind. V.	Direction.	Actual V.	Microm. Corr. to 76°.		Value in Lbs. per sq. in.	W. Comp. of V.	Remarks.
3– 1	8:00	74.0°	0.569	10	W.	9.6	0.588	Subtract 0.600 from all readings.	– 157	9.6	
1	4:45	73.8	0.598	14.5	W.S.W.	13.0	0.619		249	12.0	
2	8:25	73.0	0.608	15	W.	13.5	0.637		484	13.5	
2	3:55	73.0	0.639	27	W.	23.3	0.668		890	23.3	
3	3:00	74.8	0.664	9	W.	8.6	0.675		982	8.6	
4	7:55	75.7	0.656	12.5	N.W.	11.7	0.659		773	8.3	
6	7:40	75.8	0.670	20	N.	17.8	0.672		943	0	Reset microm. Reads 0.315 after.
6	4:05	76.2	0.328	10	N.E.	9.6	0.681		1,061	– 6.8	
7	7:15	75.2	0.352	15	S.E.	13.5	0.715		1,506	– 9.6	
7	4:05	76.0	0.362	15	N.E.	13.5	0.717		1,533	– 9.6	
8	7:30	74.2	0.335	9	E.N.E.	8.6	0.707		1,402	– 8.0	
8	4:30	76.5	0.362	5	S.S.E.	5	0.712		1,467	– 1.9	
9	7:55	76.2	0.366	10	S.S.E.	9.6	0.719		1,558	– 3.7	
9	3:45	77.4	0.361	14	S.	12.6	0.703		1,349	0	
10	7:25	77.0	0.313	5	W.	5	0.658		760	5	
10	3:50	77.2	0.302				0.645		590		
10	4:55	77.0	0.314				0.659		773		
11	8:12	76.8	0.356	16	E.N.E.	14.4	0.703		1,349	–13.4	
13	7:28	74.8	0.246	12	W.	11.5	0.613		170	11.5	
13	4:05	76.8	0.284	15	E.N.E.	13.5	0.631		406	–12.5	
14	7:30	76.3	0.309	4	E.	4	0.661		799	– 4	
14	3:50	76.7	0.322	5	S.W.	5	0.670		917	3.5	
15	7:30	76.0	0.305	9	W.	9	0.660		786	9	
15	10:40	75.6	0.318	38	N.W.	31.6	0.677		1,009	22.4	
15	3:05	75.4	0.319	40	N.W.	33.3	0.680		1,048	23.6	
16	7:53	72.4	0.374	15	W.	13.5	0.763		2,135	13.5	
16	3:22	72.0	0.397	10	W.	9.6	0.790		2,487	9.6	Changed extensometers Mar. 20.
17	4:03	74.0	0.470	17	S.	15.3	0.844		3,195	0	Readings *do not connect.*
20	4:03			23	N.W.	20.2	0.339	Add 0.100 to readings.	5,755	14.3	Rubber band placed over lever.
21	7:42	76.0	0.399	2	S.E.	2	0.416		6,760	– 1.4	Remains on till end.
21	3:42	76.0	0.399	19	W.S.W.	17.0	0.399		6,545	15.7	
22	7:41	76.0	0.361	18	W.	16.2	0.361		6,035	16.2	

For Column 13.

Date.	Time.	Col. T.	Microm.	Ind. V.	Direction.	Actual V.	Microm. Corr. to 76°.		Value in Lbs. per Sq. In.	W. Comp. of V.	Remarks.
3–22	3:32	76.6°	0.343	34	N.	28.7	0.337	Add 0.100 to all readings before converting into unit stress.	5,725	0	
23	7:44	73.7	0.336	20	N.W.	17.8	0.358		6,000	12.6	
23	3:49	73.1	0.343	20	N.	17.8	0.371		6,165	0	
24	8:04	72.3	0.376	9	N.E.	9	0.411		6,700	− 6.4	Quick drop of lever soon as plunger was pushed up.
25	7:38	72.0	0.453	7	S.E.	7	0.491		7,740	− 5.0	
27	7:48	76.8	0.343	30	S.S.W.	25.7	0.335		5,700	9.9	
27	10:22	76.7	0.338	33	W.	28.0	0.331		5,645	28.0	Rubber band on 30 min. tests. Less than 0.001 in. movement under steady observation.
27	11:00	76.7	0.343	28	S.W.	24.1	0.336		5,715	17.0	
27	4:15	75.9	0.341	15	W.	13.5	0.342		5,785	13.5	
27	9:47 P.M.	75.0	0.347	20	N.W.	17.8	0.357		5,980	12.6	
28	8:13	72.7	0.392	13	W.	12.5	0.424		6,865	12.5	
28	3:46	73.0	0.414	5	W.	5	0.443		7,120	5	
29	7:47	73.1	0.429	9	E.	9	0.457		7,300	− 9	
29	3:33	74.0	0.414	2	W.	2	0.433		6,985	2	
30	7:52	73.7	0.376	10	W.	9.6	0.398		6,530	9.6	
30	3:37	73.4	0.371	9	N.W.	9	0.396		6,500	6.4	
31	7:03	72.8	0.379	5	W.	5	0.410		6,685	5	
31	3:40	73.0	0.415	5	W.	5	0.444		7,130	5	
4– 1	11:40	73.0	0.431	7	N.W.	7	0.460		7,340	5	
3	7:30	72.8	0.534	22	E.	19.4	0.565		8,710	−19.4	
3	7:37	72.8	0.536	22	E.	19.4	0.567		8,735	−19.4	
3	7:47	72.8	0.534	22	E.	19.4	0.565		8,710	−19.4	
3	4:07	73.8	0.534	11	E.	10.5	0.555		8,580	−10.5	
4	8:00	74.7	0.507	10	S.E.	9.6	0.519		8,110	− 6.8	
4	3:35	76.0	0.468	15	S.E.	13.7	0.468		7,450	− 9.7	
5	7:25	76.8	0.314	27	S.W.	23.3	0.306		5,315	16.5	
5	8:10	76.8	0.312	20	S.W.	17.8	0.304		5,295	12.6	
5	3:28	77.9	0.313	22	W.	19.4	0.295		5,175	19.4	
6	7:22	77.5	0.314	12	S.	11.5	0.300		5,240	0	
6	3:19	77.7	0.305	22	W.	19.4	0.289		5,100	19.4	
7	7:40	75.0	0.279	5	N.	5.0	0.289		5,100	0	

For Column 13.

Date.	Times.	Col. T.	Microm.	Ind. V.	Direction.	Actual V.	Microm. Corr. to 76°.	Value in Lbs. per Sq. In.	W. Comp. of V.	Remarks.
4–7	3:21	75.5°	0.279	4	N.	4.0	0.284	5,030	0	Top clamp worked loose. Reset 0.258
8	7:37	75.0	0.284	7	N.	7.0	0.315	5,435	0	
8	2:56	75.4	0.310	20	N.	17.8	0.337	5,725	0	
10	7:05	75.0	0.369	12	E.	11.5	0.400	6,550	−11.5	
10	3:53	76.0	0.408	12	S.E.	11.5	0.429	6,935	− 8.2	
11	7:25	76.0	0.422	10	S.E.	9.6	0.443	7,115	− 6.8	
11	3:49	76.8	0.448	11	S.E.	10.5	0.461	7,350	− 7.5	
12	8:09	75.5	0.325	20	S.E.	17.8	0.351	5,905	−12.6	
12	3:30	76.5	0.309	17	S.	15.3	0.325	5,570	0	
13	7:40	76.5	0.272	17	S.E.	15.3	0.288	5,085	−10.8	
13	3:00	77.8	0.245	20	S.	17.8	0.249	4,570	0	
14	7:27	77.5	0.179	26	N.W.	22.4	0.186	3,747	15.9	0.287 = Reading after resetting micrometer.
14	7:33	77.5	0.287	31	N.	26.5	0.186	3,747	0	
14	3:47	77.5	0.284	15	N.W.	13.5	0.183	3,707	9.6	
15	7:21	76.0	0.283	14	W.	12.5	0.196	3,880	12.5	
17	7:04	76.0	0.376	10	N.	9.6	0.289	5,100	0	
17	3:58	76.3	0.379	12	N.	11.5	0.289	5,100	0	
18	7:03	76.0	0.406	7	S.E.	7.0	0.319	5,490	− 5.0	
18	3:26	76.8	0.403	10	S.	9.6	0.308	5,350	0	
19	7:42	76.0	0.400	15	S.E.	13.5	0.313	5,420	− 9.6	
19	3:10	77.3	0.361	8	W.	8	0.262	4,740	8.0	
20	6:46	76.7	0.316	20	N.	17.8	0.222	4,220	0	
20	3:28	77.2	0.316	15	N.	13.5	0.217	4,150	0	
21	7:35	77.2	0.331	4	N.	4.0	0.232	4,350	0	
21	3:10	78.0	0.335	10	N.	9.6	0.229	4,310	0	
22	7:12	76.0	0.335	16	N.	14.4	0.248	4,560	0	
22	3:30	76.0	0.335	20	N.	17.8	0.248	4,560	0	
24	7:10	75.0	0.383	9	N.	9	0.306	5,320	0	
24	3:48	76.3	0.428	13	N.	12.5	0.338	5,745	0	
25	7:14	75.2	0.427	8	N.	8	0.348	5,875	0	
25	2:38	76.5	0.480	5	E.	5	0.388	6,400	− 5	

Add 0.100 to all readings before converting into unit stress.

For Column 13.											
Date.	Times.	Col. T.	Microm.	Ind. V.	Direction.	Actual F.	Microm. Corr. to 76°.		Value in Lbs. per Sq. In.	W. Comp. of V	Remarks.
4–26	3:32	76.0°	0.529	5	S.E.	5	0.442	Add 0.100 to reading.	7,100	− 3.5	
27	7:17	76.0	0.464	10	S.E.	9.6	0.377		6,250	− 6.8	
27	3:34	75.0	0.477	10	S.E.	9.6	0.400		6,550	− 6.8	
28	7:35	75.5	0.388	7	S.	7	0.306		5,315	0	
28	3:41	75.0	0.353	11	S.W.	10.4	0.276		4,930	7.4	
29	7:22	75.0	0.230	12	S.	11.5	0.153		3,315	0	
29	4:46	75.0	0.185	10	S.S.E.	9.6	0.108		2,723	− 3.7	Microm. reset. Reads 0.463 after.
5– 1	9:08	75.0	0.334	23	S.	20.2	−0.021		1,035	0	
1	4:08	74.7	0.330	52	W.	42.2	−0.023		1,008	42.2	7.17 lbs. per sq. feet press. on west wall.
2	8:08	72.5	0.324	14	N.N.W.	13.4	−0.007		1,219		
2	3:44	73.0	0.322	13	N.	12.5	−0.014		1,127	0	No variation noticeable.
3	7:40	73.2	0.324	3	N.	3	−0.014		1,127	0	
3	3:31	74.3	0.322	9	N.W.	9	−0.026		970	6.3	
4	7:19	74.0	0.322	6	N.	6	−0.024		997	0	
4	2:11	75.2	0.319	10	N.	9.6	−0.038		813	0	

N. B. An accident, May 1, prevented vibration and deflection readings during highest wind.

DISCUSSION OF RESULTS.

It is very quickly apparent that there are very large unit stresses in both these columns which can not in any way be attributed to wind pressure. In fact, during each high wind recorded above careful readings were made on the micrometers and no variations of as much as 0.001 in. could be detected over periods of thirty minutes of observation, on either Column 11 or 13. The writer noticed however that *after* a high wind the reading would usually increase with a jump; this, together with the fact that a high wind was usually followed by colder weather, suggested temperature variation as the cause of the stress variation in the column. By this is meant the variation in the temperature of the outside air and not the column temperature, which has already been corrected for, as shown in the above tables. In order to present the relation between the variation in column stress and the atmospheric temperature the curves of Fig. 29 have been constructed. The solid irregular series of straight lines represents the variation of stress in Column 13 and the solid irregular curved line represents the variation of temperature. The curve of wind velocities has not been shown since there can be no doubt but that it is not at all related to the stress curve.

An attempt will now be made to explain the curve for column 13. Column 11 is in the west wall of the building, while Column 13 is in the party wall between structures *A* and *B*. Any change of outside temperature will affect column 11 before reaching column 13, even though there is a small air space between the walls of the two structures *A* and *B*. Now, when a decrease of temperature was experienced it was noted that column 13 stretched, *i. e.*, that the micrometer readings increased, and vice versa for an increase of temperature. Another fact noted was that the change in the column stress did not take place immediately after a change of temperature, but that there appeared to be a lag in the effect on the column. In Fig. 29 the dotted line shown is an attempt to average the temperature curve: the intersections of the straight average temperature slopes are lettered and on the stress line for column 13 are marked by these letters, with a prime, the points which the writer considers to correspond with the same lettered

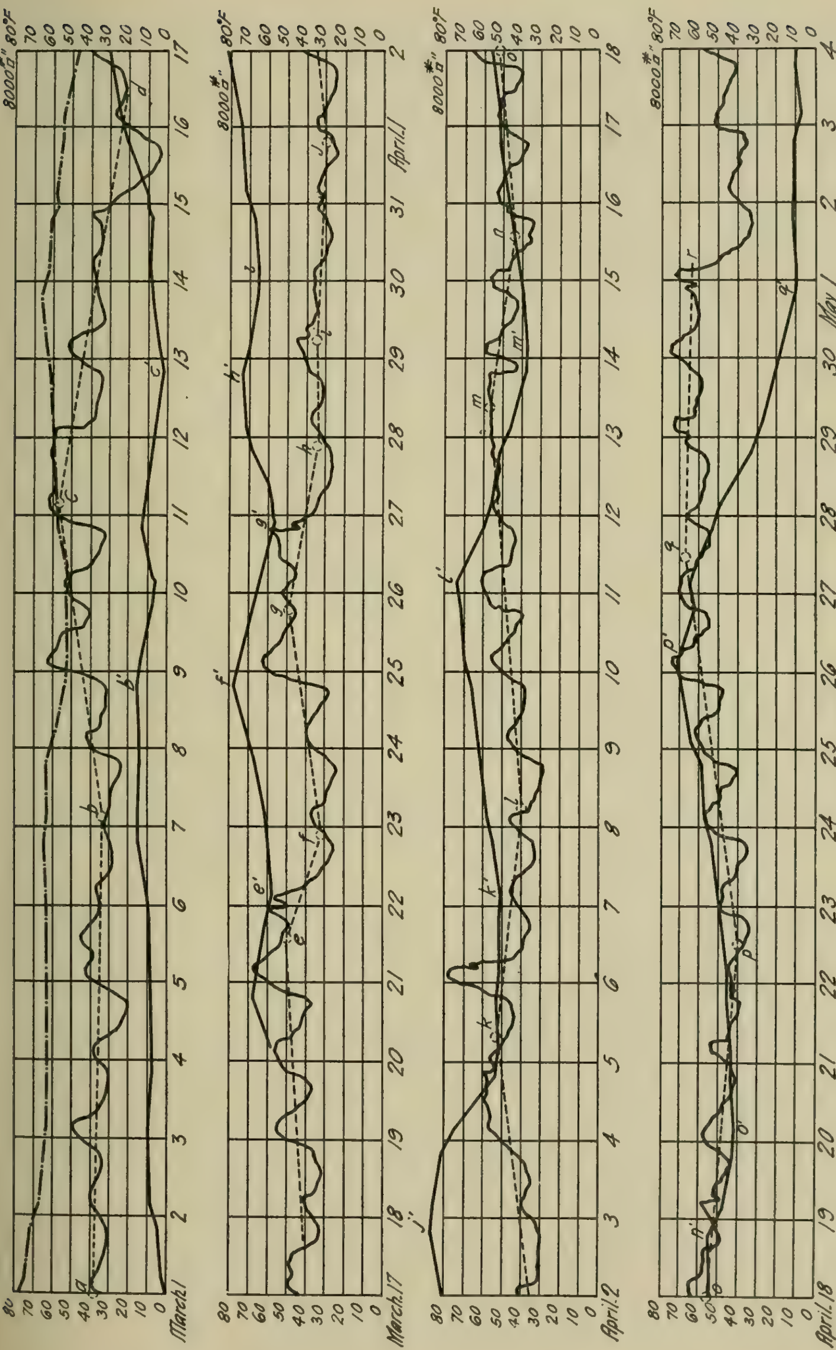


FIGURE 29

point on the temperature line. Thus l' on the stress curve corresponds to l on the line of average temperature slopes. This means that the temperature, starting on a gradual increase at 6 P. M., April 8, does not affect column 13 until 4 P. M., April 11, or almost three days later, when the stress change becomes compressive. Stresses measured upwards in Fig. 29 are really tensile or represent a decrease in the column unit compressive stress. Thus, for every rise in the average temperature line there should be a corresponding fall in the stress curve and this seems to be proven in the figure without an exception. The amount of lag will be seen to vary from about a day to three days. Large changes of temperature of only short duration seem to have little effect on the column, but a steady change extending over about a week's time may cause a most serious range of column stress. For example note the effect of the warm wave of April 22–27 and the effect on the column 13 from April 26 to May 1, a range of over 6,000 pounds per square inch. These stresses are not only large, but they are alternating and have an effect similar to varying the load on the structure. The creaking of this building has been a very noticeable feature since its erection, and this is undoubtedly merely audible evidence of the stresses which must exist.

Now, since the instruments were only applied to the inner extreme fibre of the column, there is no way to tell whether the fibre stresses recorded above are due to bending or due to a uniform axial column stress. The writer assumes them to be uniform axial column stresses for the following reasons:

It has been shown from Fig. 29 that a drop in temperature will, after a lapse of from one to three days, produce tensile increments or a decrease in compressive stresses and likewise a rise in temperature causes compressive increments. Referring now to Fig. 30, suppose Column 11 to be shortened by the decrease of temperature which does not, however, directly affect column 13, since it is protected by structure B. If no resistance were offered to this shortening, the amount of the shortening would be AA', say: but the point B, on column 12, acts as a fulcrum for the lever composed of the girders AB and BC and, while there will be sufficient freedom in the connections of the beams to allow column 11 to contract

almost freely for a certain distance, when this limit is reached the lever AC comes into play and any further contraction will produce tensile increments, or a stretch, in Column 13, as was found in the experiments for that column. As soon as stress starts up in column 13, a similar stress (tensile), equal to b'/b times the total induced stress in column 13 will exist in column 11. This tensile stress in column 11 will offset part of the contraction of that column and an extensometer applied to the column will register the real or resultant shortening of the column. It may then be said that the free con-

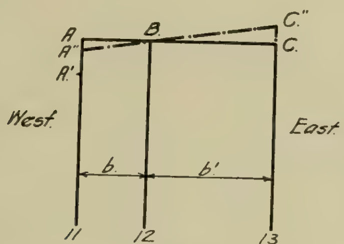


FIG 30

traction that would ensue from temperature alone equals the shortening as shown by the extensometer plus the tension elongation due to b'/b times the total induced stress in column 13. There will also be some energy taken up in deforming the beam AC. It will be seen then that when the temperature falls Column 13 will not be affected until the freedom in the connections is first taken up and then the flexure of the beam AC will continue to cause a small lag in the effect on column 13. Similar results would ensue if the temperature were to rise. In the following table the stress change in Column 13 has been multiplied by b'/b times the ratio of the area of Column 13 to that of column 11 (basement story) and added to the "stresses" as already given for column 11, after first subtracting these latter figures from 5,150, as so to make the resultant reading for March 1, at 8 : 10, zero. These resultant unit stresses have been converted into degrees of temperature (F.) by dividing by

$$\frac{0.0000067 \times 42.75 \times 13.1 \times 50}{0.001} = 188.$$

These figures then represent the fall of temperature required to produce the effects noted. Subtracting all these figures from 80° gives a curve supposed to agree closely with the temperature curve plotted from the thermograph records. It is to be noted that the experiments on Column 11 ran only up to March 17; they were then discontinued because the extensometer was thought not to be working properly.

Col. 13 Stress.	$\frac{b'}{b} \times$ Col. 13.	5150—Col. 11.	Sum.	°F.	80 °F.
− 157	− 290	+ 290	0	0°	80.0°
249	460	640	1,100	5.8	74.2
484	895	775	1,670	8.9	71.1
890	1,645	970	2,615	13.9	66.1
982	1,817	1,520	3,337	17.8	62.2
773	1,425	1,890	3,315	17.6	62.4
943	1,740	1,522	3,262	17.3	62.7
1,061	1,960	1,287	3,247	17.2	62.8
1,506	2,780	325	3,105	16.5	63.5
1,533	2,825	670	3,495	18.6	61.4
1,402	2,590	723	3,313	17.6	62.4
1,467	2,710	1,533	4,243	22.5	57.5
1,558	2,880	2,346	5,226	27.8	52.2
1,349	2,500	3,003	5,503	29.2	50.8
760	1,405	4,010	5,415	28.8	51.2
590	1,090	4,155	5,245	27.8	52.2
773	1,427	4,155	5,582	29.7	50.3
1,349	2,500	2,177	4,677	24.8	55.2
170	314	3,250	3,554	18.8	61.2
406	750	2,490	3,240	17.2	62.8
799	1,477	1,273	2,750	14.6	65.4
917	1,693	1,864	3,557	18.9	61.1
786	1,450	2,270	3,720	19.8	60.2
1,009	1,865	2,555	4,420	23.5	56.5
1,048	1,940	2,360	4,300	22.8	57.2
2,135	3,950	1,150	5,100	27.1	52.8
2,487	4,600	720	5,320	28.2	51.8
3,195	5,900	1,115	7,015	37.3	42.7

The curve just mentioned is shown in Fig. 29 by a dash-dot symbol; it does not show the intimate relation to the thermograph record that was expected and, in the absence of further experiments, the writer can make no satisfactory explanation of the disagreement. Much confidence is, however, expressed for the results of the readings on column 13 and the deductions already given. If the principle illustrated in Fig. 30 represents existing conditions properly then the Column 12 must have a range of stress of at least 22,000 pounds per square inch. It must be explained here that

the writer has been handicapped for time on this work; all of the investigation results, formulae, tables, experiments and in short this entire manuscript has been prepared since Jan. 1, 1911. (Many preliminary studies, theoretical methods and attempted solutions were undertaken during the previous year, extending intermittently from September, 1909, until the date of starting this manuscript.)

In conclusion, these experiments surely indicate that a most complete and extensive series of experiments are of the highest importance and that information on the temperature stresses in tall buildings is of much greater importance than are investigations of the effect of wind pressure on such structures. Experiments for securing this information must be on a very elaborate scale and cover a period of one year to determine the general effect of seasonal changes: it is not believed, judging from Fig. 29, that a change in the season will produce, of itself, any effect, but rather that the temporary changes of temperature of several days' duration account for most of the stress produced.

CHAPTER XVI.

CONCLUSIONS.

All references in this chapter are to be understood as applying to a portal braced structure.

A. The Practical Value of a Correct Theoretical Analysis of the Stresses in Tall Buildings.

Referring to the plates of Chapter III and the applications in succeeding chapters it will be seen that, for the ordinary tall building, the accurate solution of stresses involves considerable labor and the *time* required for computing stresses, to say nothing of revisions after the original computations on account of revised design, makes the accurate solution of such stresses of an *entirely impractical nature.* The writer does not believe there is any shorter cut possible for the accurate determination of stresses. It is then concluded that it is impracticable to design a high building by any correct theoretical method but that, from the application of the method of Chapter III to various types of structures under various loadings, empirical rules can be deduced, which, when applied to similar cases, will give quick and closely approximate results. It is suggested that such a large work might be systematically divided up and be undertaken as undergraduate theses in technical schools and universities.

B. A Summary of the Effect of Wind on a Structure.

(*a*) *Wind Loads.*—It has been claimed that pressures from 60 to 85 pounds per square foot may exist during a tornado (Baier on St. Louis tornado) and, while even a 30 pound per square foot pressure seems to be equivalent to a wind higher than recorded by the U. S. Weather Bureau, yet it is probable that a unit pressure of 30 pounds will continue to be provided for in designs, at least until more accurate and direct data for tornado pressures is obtainable. It is believed that, with the common working units for

a 30 pound pressure, the indefinite higher pressures possible will be taken care of.

(*b*) *The Value of the Simple Method of Chapter II for designing for Wind Pressure.*—For column shears, column bending moments, and girder stresses the method of Chapter II is all that can be desired for all stories above the basement, agreements closer than 10 per cent being the rule. In the basement story the method of Chapter II gives column bending moments too low, possibly as much as 50 per cent. For single story portals this discrepancy is not very noticeable and it is larger when the girders are lacking in rigidity, *i. e.*, of small moment of inertia.

For axial column stresses, the assumption that the building acts like a beam is undoubtedly incorrect, but the writer can suggest no better substitute. A very extensive study will be required to determine the laws of variation of the axial stresses. For a two column cross section the agreement is very close but the double portal calculations of Chapter XI show that the method fails for the general case.

For building deflections the method of Chapter II always gives too small results and as shown in Chapter X the ratio may be as small as 1 : 3.08.

(*c*) *Suggestions.*—The writer would suggest that the method of Chapter II be adopted entirely for the calculations of stresses due to wind; that the bending stresses in basement columns be then increased 25 per cent, all other stresses to remain as thus calculated.

C. A Summary of the Effect of Eccentric Column Loads on a Structure.

(*a*) *The Value of the Method of Chapter II in Providing for These Loads.*—It has been shown in Chapter IX that this method gives axial column stresses nearly correct for a two column cross section. In Chapter II it was shown that it is not reasonable that the method applies when there are more than two columns in a section. It was also shown in Chapter II that this method gives zero bending moments in the columns for such loadings. It is then concluded that the method of Chapter II should not be used in providing for eccentric column loads.

(*b*) *The Value of Professor Heller's Deductions on Eccentric Column Loadings.*—Professor Heller's methods give, as shown in Chapter IV, a maximum column moment occurring at the top of the structure equal to Pe and at the floors a few stories above the basement and below the roof, a nearly constant maximum of about $\frac{1}{2}$ Pe (see Fig. 7, *b*).

In Chapter IX it was found that the maximum moment in Column A ($-$ 247,049) occurred in the *second or middle story* and was equal to 0.98 Pe; the maximum moment in Column B ($+$ 174,108) occurred also in the *second story* and was equal to 1.24 Pe. At the roof with a zero eccentric load at Column B there was found a bending moment of $+$ 35,109 and, for column A, a moment of $-$ 44,191 equal to 0.33 Pe.

It is evident then that it is not safe practice to follow the conclusions deduced in Chapter IV, which are identical with Professor Heller's. It is further shown that the value of the bending moment may materially exceed even the quantity Pe so commonly used by designers. Also it is shown that the bending moment is not a constant throughout the story height but reverses in sign, and at the foot of the column it may be a much larger quantity, of opposite sign, than the moment at the top of the column.

(*c*) *Suggestions for Design. Axial Column Stresses.*—In the case of several columns in a cross section it is suggested that the axial load on the column, due to the eccentric load be taken as equal to the eccentric load plus the eccentricity divided by the span of the connecting floor girder times the eccentric load. This gives but very little of the load to interior columns, as seems reasonable in contra-distinction from the method of Chapter II.

Column Bending Stresses.—It is suggested that a bending moment not less than Pe should be provided for, and, in combining with wind and floor load stresses, this bending should be considered as existing at both top and bottom of the story and of opposite signs at these points, realizing that the stresses thus obtained may occasionally be a little small but that, for the top and bottom portions of the structure, they are probably on the safe side.

Girder Stresses.—If the girders are proportioned by the methods of Chapter II, considering that the stresses may be either plus or minus, the results will be sufficiently close (see Chapter IX).

D. A SUMMARY OF THE EFFECT OF FLOOR LOADS ON A STRUCTURE.

(*a*) *The Value of the Method of Chapter II for Designing for Floor Loads. Axial Column Stresses.*—As shown in Chapter XI, errors in the axial stresses of the main columns, on the dangerous side, for a double portal, as high as 22 per cent may occur (cf. 88,622 and 72,581). For a two column section the agreement is very close. It is not likely that errors as high as 22 per cent exist for a several column section of more than one story.

Column Bending Stresses.—The method of Chapter II gives zero bending in the columns. Here is an enormous error in the prevailing method of designing tall buildings.

Girder Stresses.—If flange sections are made uniform for the full length of the girder, then, as shown in Chapter VIII, the method of Chapter II is on the safe side in determining flange section.

(*b*) *Results Found in This Investigation. Column Bending.*—The maximum bending in a column occurs at the top of the column in the basement; at the foot in the first, at the top in the second, etc., alternating thus to the roof line.

It was shown in Chapter VIII that the unit stress in the column due to bending from uniform floor loads may be nearly *four* times that due to the axial load (*cf.* 6,415 and 1,725; also 4,865 and 1,322). In the case of similar girders and floor loadings the maximum bending moments are about the same throughout the height of the building.

The value of the maximum bending in a column may be fairly averaged without very serious error in ordinary designs by the expression $wL^2/24$ where w is the load per lineal inch of floor girder and L is the span, in inches, of the floor girder connecting to the column. In case it is an interior column the moment will be expressed as $wL^2/24 - w'L'^2/24$ where a prime designates the quantities for the extra span.

In designing the girders the flanges should be designed to properly transmit the stresses occurring at their connections to the columns. These stresses are fairly large.

(*c*) *Suggestions for Design.*—Use the method of Chapter II for axial column stresses and for determining flange areas of girders.

Provide for a column bending moment of $wL^2/24$ as noted above, at both top and bottom of the column section in computing maximum stresses from combined loads: these moments will be of opposite sign.

Design girder connections to transmit flange stresses equal to three quarters of the maximum flange stress at the center of the girder as computed by the method of Chapter II.

E. Maximum Effects of Combined Loadings.

It was shown in Chapter IX that under combined loads the maximum stresses in the extreme fibres of the columns and in the flanges of the girders will exceed those as found by the method of Chapter II by percentages increasing from the bottom to the top of the structure and it was found that these percentages reached as high as 100 per cent at the top of the building.

F. The Value and Efficiency of Knee Bracing.

In Chapter XII it has been shown:

(*a*) That the unit stresses in knee braces can not be very large; say not over about 4,000 pounds per square inch, and that the customary design, in which a large unit stress is used, is widely in error.

(*b*) That knee braces do not appreciably diminish the maximum bending in the column unless placed at both top and bottom.

(*c*) That there can be no reversal in bending moment at the bottom of the girder, as has been assumed in mathematical discussions of plate girder portal stresses.

(*d*) That when knee braces are used, top and bottom, a considerable reduction in column bending moment can be effected.

(*e*) That the size of the knees should first be assumed and the reduction in column bending moment then computed; a few simple trials will give the most desirable brace to use.

(*f*) That the simple approximate method given in the early part of Chapter XII is a practical and closely approximate one and is recommended to the profession.

(*g*) That the assumption that the shears across the columns are proportional to the moments of inertia of the columns is close enough for all practical purposes for knee braced portals.

G. EXPERIMENTAL CONCLUSIONS (CHAPTER XV).

Effect of Wind. (*a*) *Deflection and Vibration.*—It is concluded that, when proper account is taken of the velocity and pressure of the wind, that vibrations and deflections, properly computed on the basis of the steel frame resisting all the pressure, will be only slightly in excess of those actually existing. It was shown that the walls and partitions probably reduce the deflection of the seventeen story structure tested only about 40 per cent.

(*b*) *Column Stresses.*—It was found that the wind had no noticeable effect whatever on the basement columns at the points tested. However the extensometers were necessarily located in a most unfavorable position for observations for wind stresses.

It was shown that the sections in the front and rear walls, so much more rigidly braced, probably take care of almost the entire wind pressure, because of the partial inability of the interior bracing to properly transmit the bending moments at connections.

Effect of Temperature.—It was found that in five days time there was a range of stress of over 6,000 pounds per square inch and in the course of the two months experiments a total range of probably over 8,000 pounds per square inch in the column unit stress. It was shown that in all probability these variations of stress were produced by gradual changes of temperature, but that they are probably independent of seasonal changes. Indications point to a range of 22,000 pounds per square inch in an interior column (column 12) but no tests were secured to verify it.

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ELECTROLYTIC DISPOSITION OF SEWAGE

BY

F. C. CALDWELL

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ELECTROLYTIC DISPOSITION OF SEWAGE

BY

F. C. CALDWELL

The electrolytic purification of sewage is not new, patents covering the system having been taken out in England nearly a quarter of a century ago. It has however, been recently revived with such a degree of success, as makes it fitting that it should be considered by this association, to the members of which its general adoption might be of considerable importance.

The material to be handled is made up of domestic sewage, sometimes accompanied by factory wastes and more or less diluted with storm water. Domestic sewage is made up of organic matter that is animal and vegetable, partly dissolved and partly suspended in water. There are also present vast numbers of bacteria often thirty to fifty million in a cubic inch. Factory waste when present may be any one or more of many kind and affects the problem differently according to its nature. It is therefore not considered in this paper.

The degree of dilution of the sewage to be handled will vary greatly, depending both upon the habits of the population and upon the amount of storm water. In general, it is much more dilute in this country than in Europe. The large proportion of water greatly increases the difficulties of handling the sewage.

The presence and action of the bacteria constitutes one of the most important factors in the problem. They may in general, be divided into two classes, the putrifying, also called anaerobic, because they flourish without oxygen, and the oxidizing or aerobic, which as indicated by their name, require oxygen for their best development.

The putrifying bacteria operate in the sewers and in any closed reservoir or septic tank in which the sewage may be held. They are helpful in that they digest or liquify any solid portions, but to their action are due the offensive odors which characterize stale sewage. It is therefore essential that their action should be for the most part stopped before the sewage is turned into rivers or othr water.

The oxidizing bacteria on the other hand, oxidize or "burn up" the organic material reducing it to simple, stable and inoffensive matter in which condition it ceases to be a nuisance, especially when further diluted with river water. As indicated above, their action is promoted by the presence of air and goes on without offensive results even after the sewage has been turned into the river. They can, however, act only effectively upon finely divided matter, and it is therefore usually dsirable for their action to be preceded by that of the putrifying bateria.

There are also to be considered the disease producing bacteria, originating in the human body. Of these the most notable is the typhoid bacillus. These, if simply run into the river water will remain alive for considerable periods, but they do not flourish under such abnormal environment and are not difficult to eliminate. In many plants it is not considered necessary to sterilize against such bacteria except at times of epidemics.

Any system of purification, to be a success, must leave the sewage inoffensive in appearance and in odor. Practical elimination of the disease producing bacteria is also desirable. Generally, also, the sewage must be to such an extent oxidized that there will be no danger, under the conditions of its disposal of putrification again setting in. It is not sufficient to eliminate the putrifying bacteria as there are enough to be found in the river or other water to start the process and once started the rate of increase is enormous. It has been estimated that under unnaurally favorable conditions one bacterium would in twenty-four hours give rise to sixteen and one-half millions.

Granted that a new system accomplished these functions satisfactorily, it would still remain to be demonstrated that it did so more economically than other methods already available.

Before inquiring into the effectiveness of the electrolytic method it will be well to describe its operation. The following relates to the latest plant a description of which has been published, namely that at Oklahoma City, (population in 1910, about 64,000.) This plant was put in operation on March 29, 1911, and was designed to handle 750,000 gallons of sewage per day. One or more of three flumes 18x20 in cross sections and 30 feet long received the sewage. This comes from the city through a conduit about a mile in length and the flow through this is an important factor as it assists in the mechanical disintegration of the sewage as well as serving as a septic reservoir for the action of the putrifying bacteria. Each flume is designed to care for 250,000 gallons of sewage per day. The electrolysis is effected by ten groups of iron plates, each group consists of 27 plates, 3-16x10-24 spaced ½ inch between surfaces. These may be likened to the elements of a storage battery, of such size as to nearly fill up the flume, and with their faces parellel to its sides. Alternate plates are positive and negative, and are connected to bus bars run along the edges so that all the groups of plates are in parallel. The bus bars are supplied by a 3kw. motor generator set with current at from 1½ to 3 volts. Each flume takes normally 270 amperes. A reversing switch is included in the circuit, and changing the direction of the current once or twice a day equalizes the wear on the plates and removes the deposit which forms upon them.

To prevent excessive electrolysis at the upper edge a copper binding is used. The plates are gradually dissolved and take part in the chemical action upon the sewage.

The effluent is discharged into a so-called "dry gulch," and the sediment deposited in the flumes is periodically flushed out into the same gulch.

The Oklahoma plant was established on the strength of the results obtained from one installed at Santa Monica, California, population 11,000 to 18,000, depending upon the time of year, in June, 1908, and was modelled closely after it. The Santa Monica plant, however, discharges the effluent into the ocean 1,600 feet from shore. In passing, it is interesting to note the surprising lack of knowledge of things electrical evinced in the installation of this system. For example, magnets were placed over the plate electrodes for the purpose of intensifying the action of the current upon the sewage, but were easily removed.

We come to the perplexing question—Does the electrolytic method satisfactorily "purify" the sewage. Two causes of purification are claimed, namely the production chemicals which are strongly oxidizing or chlorinating in their nature and the production of oxygen itself in the so called nascent state, in which it is very active chemically. That such chemicals are formed and that they do operate to destroy the bacterial life they reach and to some extent to oxidize the organic matter itself is undisputed. The part played by the nascent gases is more doubtful as it seems to have been well established by Geo. W. Fuller in an extended investigation at Louisville (see his "Sewage Disposal," page 557,) that such oxygen is almost entirely used up in attacking the iron plates. Further the gas ceases to be nascent almost immediately after its formation on the surface of the plates and hence any direct action due to it would only take place in a very thin layer next to the plates, so that a small portion of the liquid would be affected.

An illustration of the efficacy of the electric current in the destruction of bacteria is found in some tests made some time ago by Dr. C. B. Morrey of the Ohio State University, and the author, on the electrolytic sterilization of milk. In a sample of market milk containing 19,480,000 bacteria per cubic centimeter, an application of 2.5 amp. at 2,000 volts alternating current for 15 seconds reduced this number 99.97 per cent. Another similar test showed a reduction 98.7 per cent. and at third in which the milk was inoculated with diptheria bacteria in very large numbers showed their practically complete destruction. Chemical examination of the milk showed no changes which would account for the sterilization nor could this be accounted for by the heating which took place.

The evidence seems quite conclusive that where the sewage has received suitable disintegrating and digesting or putrifying action previous to the electrolytic treatment the effluent, immediately after each treatment is practically odorless and free from baceria. The question which does not seem to be satisfactorily answered is "Has organic matter been so far oxidized that it can be relied upon not to again putrify and thus develop a nuisance in the stream through which it flows."

The experience at Santa Monica where the effluent, in comparatively small amount, is deposited in the ocean over a quarter of a mile from shore cannot be taken as indicative of the results which would follow where a comparatively small stream were made use of. The case of Oklahoma City where the effluent is run into a dry gulch is perhaps more instructive, though

even here the conditions are so different from those usually met with in this part of the country that they should not be given too much weight. There being presumably no other water in the gulch through most of the year, there might be no such supply of putrifying bacteria as would be found in most streams. Again if the soil is sandy the effluent may sink in before it has had time to develop further putrification. The effluent as it comes from the plant may be somewhat antiseptic, which would discourage the growth of putrifying bacteria for a considerable period. This condition, however, might soon cease if the unoxidized sewage were diluted in a relative small stream.

On the other hand, the advocates of the system claim that the organic material is actually oxidized or rendered nonputrescible and most of the evidence given in the published accounts is to the effect that whatever the sewage seemingly ought to do, it practically does not purify after being subject to the electrolytic treatment, and after all "the proof of the pudding is in the eating," though we might not go so far as to say that the proof of the sewage is in the drinking.

Unfortunately the available data is not sufficiently definite to enable one to apply with great confidence the results obtained at the plants already in operation to the other and different conditions elsewhere. The evidence however is certainly strong enough to warrant an interested observation of the plants already installed, even if one prefer that the other man be the next one to try the experiment.

So far the operative side of the problem alone has been considered. The economic aspects are even more difficult to pass judgment upon with the available data.

While great claims are made for the economy of the system the accounting upon which they are based does not seem sufficiently definite to be convincing. This is unfortunate since it should be entirely possible for a competent and experienced sanitary engineer to make a conclusive report based on the experience of the two plants now in operation. Such report would at least apply to conditions similar to those under which these plants are operating, though of course any new proposition would have to be considered on its own merits.

The experimental plant established at Crossness, a suburb of London, by the original inventor, W. Webster, in 1889, and which was identical in principle with those of to-day, though different in certain details, seems never to have led to any further application of the principle, though all the obtainable evidence is to the effect that it was successful in its operation. The further fact that during the twenty years following in which so many and such costly experiments were made in sewage purification, the process was never further developed by sanitary engineers is significant.

On the other hand, weight must be given to statements that the Santa Monica plant has been enlarged and that Oklahoma City is constructing a second plant with a capacity of 2,250,000 gallons. It is also to be noted

that present day purification methods are much more costly both in fixed and operating charges than those of 20 years ago and hence this system would be in a better position to compete with them. Again the fact that sanitary engineers are not usually electrical engineers may have induced them in the past to favor methods which were more familiar to them.

The following cost data are taken from the reports published in the electrical press.

First cost of Santa Monica plant (2 flumes, 550,000 gal.) including pumps, buildings, and forebay, $18,000. Monthly expenses of operating, including pumping $400. Cost of energy for the year 1909, $159.95, at three cents per kilowatt-hour. Two men are employed at $85 per month but they do other work for the city. The proposal for a filtration plant to do the same work was:

First cost of Oklahoma City plant, $16,000 (cut about 20 per cent below this figure in order to introduce the plants.)

Operating Costs.

	per annum	per mil. gals.
Current (at 5 cts.)	$709.50	$ 2.59
Attendant	660.00	2.41
Lights	40.00	.15
Renewal of plates	200.00	.73
Depreciation	100.00	.37
Interest, 5%	800.00	2.92
	$2509.50	9.17
Sinking fund, (5%, 20 year)	1000.00	3.64
	$3509.50	$12.81

Another process also invented by Webster, which employs electricity and was extensively exploited in 1894, makes use of an antiseptic solution produced electrolytically from sea water or salt solution. It seems to have been conclusively demonstrated that such solution has no advantage over antiseptics bought from manufacturing chemists and is more costly for ordinary conditions. Improvements in this method recently suggested by W. B. Ball, but still in an experimental stage may alter this situation.

Another interesting development is the use of ozone electrically produced for sewage purification. It is claimed that 215 grams of ozone can now be produced per kilowatt hour by the Meeker ozonizer and that a contract for a complete sewage treatment plant has been entered into with the city of Trenton, N. J. No data are at present available.

In conclusion it appears that the verdict for the electrolytic purification of sewage must be at the present time "Not proven, but very interesting."

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THE OHIO STATE UNIVERSITY BULLETIN
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The Effect of Lime Sulphur Spray Manufacture on the Eyesight

BY

JAMES R. WITHROW

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THE EFFECT OF "LIME-SULPHUR" SPRAY MANUFACTURE ON THE EYESIGHT.[1]

By James R. Withrow.

About two years ago, the writer was called upon to take charge of the installing of a "Lime-sulphur" department for a manufacturer engaged in other lines of chemical manufacturing. Preliminary to starting industrial experimentation, a very thorough laboratory study had been carried out by the manufacturer's regular chemist. This work reviewed in a most capable manner about all the recommendations of recent chemical and experiment station literature concerning "lime-sulphur" preparation. As a result of this work a formula was evolved, which was used as a basis for manufacturing experiments. The laboratory experiments themselves were never made in larger than five-gallon apparatus. The writer witnessed, from time to time, these experiments or portions of them and at no time noticed anything causing discomfort. The laboratory assistant, who did most of the experimental work for the company's chemist and was constantly in contact with the material and its fumes, never noticed any effect or discomfort at any stage of the laboratory work, which extended through several months. To be sure, there was the ever present odor of hydrogen sulphide or at least a similar odor. This was never offensively strong. At no time was it so noticeable as to compel enforced ventilation.

The writer's business was to accept the work as completed in the laboratory and transfer it to factory operation. The first factory experimental runs were made on about a 12-barrel scale. These experimental cooks were made to get factory scale data for construction work and also to uncover any unforeseen operation difficulties. The product had varying specific gravity from 45° to 32° Bé., depending on the purpose of the experiment. The final solution of calcium polysulphide or so-called "lime-sulphur" contained about 25 per cent. sulphur and about the equivalent of 10 per cent. calcium oxide, when the specific gravity was about 33° Bé. Twelve barrels of this product therefore would contain 1625 pounds of sulphur and the equivalent of 650 pounds of lime.

[1] Paper presented at the Eighth International Congress of Applied Chemistry, New York, September, 1912.

The first few cooks aroused no comment from employees about the building, which was a large one of four stories, beyond what would come from persons unaccustomed to hydrogen sulphide. In the course of the next week or two, however, the weather had become quite cold and the normal ventilation by means of the windows was much diminished. Again no particular effect was noticed at first. The "cook" digester was a steam jacketed cylindrical tank roughly $5' \times 5'$ and supplied with a cover and a small ventilating pipe. This pipe was inadequate for proper ventilation of tank and would have been useless anyway, for the top of the "cook" tank was usually open during the experimental runs for observation purposes. The man in charge of the cooks usually stationed himself at the opening to become familiar with boiling conditions within the tank during the various runs under different conditions.

Within a cook or two, after the windows were closed to diminish the cold conditions, the man in charge of the cook became aware of a smarting sensation in and around the eyes. The eyelids became red. The writer was constantly about the tank, but was only occasionally at the tank opening and felt little or no discomfort, though there was a slight burning feeling about the eyes. The room became partially filled with condensed steam at times and finally about 8.00 P.M., during a slightly prolonged run, the writer noticed that the amount of vapor in the room was greater than usual and that the incandescent electric lights had a halo of some eighteen inches in diameter when viewed through the fog: the halo tended to have rainbow colors. An hour or two afterwards, the writer found the same conditions as to fog and halo to exist in his room in his hotel and concluded that his eyesight was affected. Cold water was applied liberally and he turned into bed and went to sleep at once. In the morning the blurred eyesight was about as bad as the evening before. The foreman, who stood at the opening of the cook tank, had gone home at the end of the run at the time the writer did. He was unable to report for work next day. His eyes were much inflamed and were too sensitive to light to open them. He said they pained and felt gritty under the eyelids. He was back at work again in a couple of days. In the case of the writer, with the liberal use of saturated boric acid solution, the blurred vision gradually returned to normal during the course of a week's absence

from the manufacturing operation. There was a recurrence of the blurred effect at another time, which rendered vision almost impossible, but it rapidly wore off and at no time was there any pain. The foreman never again had an attack after his initial experience. None of the workmen were affected after proper precautions were taken.

At one time however, when a batch was being concentrated by boiling down, the cover was thrown open to expedite evaporation. In the same room some distance away, two workmen were barreling off finished product. Both the foreman and myself were actively engaged about the cook tank and were practically unaffected. Of the two workmen mentioned however, the thin one was very much affected and said he suffered agony all night and next day, while the corpulent one was entirely unaffected. Other workmen were in and out during the cook but none were affected. The one of the two mentioned above as unaffected has, since starting regular operation in the new plant and in fact during the rest of the experimental runs, been in active charge of the "cooks" and has never become affected, beyond possibly a slight reddening of the eyes.

No one at all has been affected in anyway since the new plant was installed with its ample facilities for ventilation. Inquiry directed to other manufacturers disclosed similar experiences. One manufacturer's experience was so bad that he at once knocked one side out of his cooking room. This is undoubtedly effective, but from the writer's experience unnecessary. All that is required is a hood over the cook tank, which will carry all vapors out doors, and a "cook" room which is high ceilinged and reasonably well ventilated. Providentially the copious evolution of steam has caused most plants to provide hood-covered tanks, thus avoiding the unexpected trouble we are discussing.

A search of the literature of "lime-sulfur" available to the writer found no mention of the effect of the eyes. The suggested reactions to explain the action of sulfur on calcium hydroxide and water, varied as they were, gave no clue to what might have been the body which gave rise to the trouble. During a subsequent study of polysulfide literature in general, however, it was found that Bloch and his pupils[1] had prepared polysulfides of hydrogen of the formulas

[1] *Ber. d. chem. Ges.*, **41**, 1961; *Am. Chem. J.*, **41**, 155.

H_2S_3 and H_2S_2. The latter is formed by heating the former and is easily volatile. The fumes of these polysulfides are said to have a penetrating disagreeable odor and their vapors attack the mucous membranes. Thorpe says their vapors attack the eyes.[1] They are decomposed by alkalies and therefore would not exist very long in the lime-sulfur cook, but if they were being given off in mere traces, continuous exposure to such fumes would naturally cause discomfort.

Hydrogen sulfide itself, however, may have been the cause of the trouble. It has been shown to be a product of the evaporation of a solution of calcium polysulfides.[2] Hydrogen sulfide could not likely have been the cause, unless the symptoms of H_2S poisoning recorded are the effects of only sudden or brief exposure to large amounts of the gas and that prolonged exposure to dilute H_2S would cause a different series of violent symptoms. This latter assumption does not appear probable for in such cases where H_2S was permitted in the atmosphere of laboratories in small amounts, the *usual* symptoms, only not so pronounced, were the result. The only recorded symptom of hydrogen sulfide poisoning observed in the cases under discussion was the occasional occurrence of headache. This was to be expected, since hydrogen sulfide was itself being evolved to some extent.

It should be mentioned, however, that K. B. Lehmann[3] mentions cases where "intense irritation of eyes, nose and throat" occurred within five to eight minutes of exposure to a concentration of 0.3 per thousand of hydrogen sulfide, but no affection of the sight is mentioned even in this extreme case. In long exposure to lower concentrations, such as would correspond with the case of hours of exposure in lime-sulfur cooking, the action recorded is on the respiratory tract. These symptons appeared entirely absent in the lime-sulfur cases as also were all the other common symptoms (except headache), such as muscular weakness, etc. A tendency to conjunctivitis, a symp tom of chronic hydrogen sulfide poisoning, may have been present in the case of the man in charge of the cooks. He was the man, however, whose eyesight itself was never affected. The writer has suffered at other times in the last six years, most of the symptoms of slow hydrogen-sulfide poisoning, due to inadequately

[1] *Dict. Applied Chem.*, **3**, 699 (1893).

[2] Divers, *J. Chem. Soc.*, **1884**, p. 284.

[3] Arch. F. Hygiene, Bd. XIV, 1892, 135; Blyth, "Poisons, Their Effects and Detection," 3rd. Ed., C. Griffin and Co., London, p. 73.

ventilated, over-crowded and poorly arranged university laboratories, but the symptoms in the lime-sulfur experience were quite different. In fact the usual muscular weakness and general depression as caused by hydrogen sulfide were not experienced at all in the lime-sulfur manufacture. It should be mentioned also, that the writer has been informed that attendants at "sulphur" baths have had their eyesight temporarily affected in a similar fashion. Volatile polysulphides may be present in this case also, although they have not been proven to the writer's knowledge to be present in either case. This would be an interesting point for some favorably situated person to develop.

It seemed possible therefore that these hydrogen polysulphides might have been the cause of the action on the eyesight of the vapors from the boiling of a mixture of sulphur, lime and water.

It may be stated at this point that this indication of the presence of hydrogen polysulphide in the vapors of the lime-sulphur cooks might have an influence upon the solution of the problem of the actual reactions involved in lime-sulphur preparations, a mooted question at the present time. The trouble with the eyesight always came when a batch was being concentrated by evaporation before filtration and not during ordinary cooks.

It seemed worth while to record these facts as a warning, at least, as to the serious dangers of lime-sulphur manufacture in the absence of adequate ventilation. This is all the more necessary since it is probable that attention has not already been frequently called to the matter, because ordinary ventilation precautions only, are necessary to avoid all trouble, and therefore the average manufacturer has not had the experience or it has appeared so seldom that the isolated affections of a workman now and again may have been attributed to something else. It is worth noting also because the mere occurrence of a cold spell of weather gave the opportunity of experiencing this difficulty possible in lime-sulphur manufacture, so that otherwise it might never have occurred at this plant or only in such isolated cases as to destroy any connection between cause and effect.

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THE PRESENT STATUS OF THE WOOD TURPENTINE INDUSTRY

BY

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THE PRESENT STATUS OF THE WOOD TURPENTINE INDUSTRY[1]

By E. H. French and James R. Withrow

In treating a subject that has as many phases as this one, it will be necessary to discuss briefly an allied industry, namely, that of Gum Turpentine as distinguished from Wood Turpentine, in order that the reasons calling for the development of this latter industry may be seen with the proper perspective.

That the Wood Turpentine Industry is at present at an extremely low ebb is unquestionably true. Nevertheless, it is likewise true that its scientific development is an economic necessity for certain localities, in order that waste may be conserved, that the products from waste replace those from the fast disappearing pine and fir forests and that cut-over land may be cleared at a profit instead of at a loss. Therefore, in this instance, as is often the case, necessity compels development.

The fact that thousands of dollars have been expended and lost in the incubation of this industry has been due, in our opinion, to three main causes, any one of which in itself would account for failure: *first*, the lack of practical scientific engineers experienced in this or analogous fields; *second*, financing for the sale of stock and securities rather than product; and *third*, lack of efficient marketing organization. It must also be borne in mind, that owing to the number of different processes, there was caused a lack of uniformity of product, which naturally tended to increase selling costs. Except to the U. S. Navy, little, if any, wood turpentine has been sold on thorough specifications. There has as yet been no real attempt by manufacturers to effect a general standard, although a few years ago the producers of the practically defunct steam process turpentine did make an attempt to standardize their product.

One of the important influences that tended at first toward the development of the industry and later proved extremely detrimental, was the speculative nature of the naval stores market. This was made up entirely of gum turpentine and rosin, upon the prices of which the relative wood turpentine values were determined. This market in the past has been subject to violent price changes, a fluctuation of from 30 cents to over $1.00 per gallon having been experienced, which was due almost wholly to speculation. Naturally, therefore, during the upward swing of prices an unnatural development occurred, and plants using costly processes and with inefficient management were profitably operated and exploited. It followed, of course, that when the national government, through criminal prosecution, put a stop to excessive speculation, a corresponding

[1] Presented at the 6th Annual Meeting of the Amer. Inst. of Chem. Eng., The Chemists' Club, New York, December 10–13, 1913.

reaction occurred, ruining many concerns which required abnormal prices for financial success.

Unreasonably high prices not only encouraged the development of the wood turpentine industry, but also caused an expansion in operations by the gum turpentine manufacturers so that a larger percentage of trees, and many very young trees, were boxed, causing overproduction.

GUM TURPENTINE

The method of producing oil of turpentine from the resins of coniferous trees, consists in cutting a broad wedge-shaped notch or cup at the base of the tree and removing the bark immediately above the notch for about 18 to 24 inches. The resin exuding from the peeled area runs into the cup at the bottom and is collected from time to time. Each succeeding season the barked area is increased until it reaches about the height of one's head, usually taking five or six years. As many as four "boxes" are thus cut on one tree, depending on its size, permitting only enough of the original bark to remain to prevent the death of the tree.

After collecting sufficient quantity of the resin, it is distilled in a copper still, usually a "fire still," equipped with a live steam jet or a water supply. The turpentine thus produced is not carried farther in any refining process, but is ready for the market. The residue in the still is the rosin of commerce and is barreled at the still. The dross obtained by filtering sticks, dirt, etc., from the rosin is in many places being worked into cheaper grades of rosin. With rosin at an average price, it is generally figured that to make the operation profitable, about 42 cents per gallon must be obtained for the turpentine.

The marketing of the products is done through "factors" as they are called; that is, companies or individuals who contract with the producers for their output, supply them with funds for pay-rolls, etc., and advances when necessary. These "factors" take the product when produced, but usually have no other connection with the producer. Savannah, Georgia, is the leading naval stores center in the world and usually Savannah prices are accepted as the standard. Jacksonville and Pensacola, Florida, Brunswick, Ga., and New Orleans, La., are also large "factor" centers for this industry.

This method of producing turpentine is generally conceded to give the best turpentine and rosin, but unless more scientific methods are very widely adopted the time is rapidly approaching when it will be necessary to supply these products from another source, for present methods of operation are beginning to be looked upon as directly antagonistic to all ideas of conservation under American lumbering conditions, as they so weaken the trees that the loss from windfalls is extremely large. In fact, many large lumber companies have given up "boxing" for this reason, and also because they feel that the growth of the young tree is retarded.

Modifications of the old "boxing" methods are being used in some places. Metal cups are substituted for the box cut in the

base of the tree and light chipping is being tried. It is claimed that the loss from windfalls is considerably reduced by some of these modern improvements. At least one large Southern lumber company is at present experimenting on 5,000 acre units in order to determine definitely, if possible, the merits of these new cups and other modifications as to yield and influence on windfalls, and also to decide the effect "boxing" may have on finished lumber.

WOOD TURPENTINE

Wood Turpentine came into commercial notice about the year 1900. The name was, and is, applied to the product obtained from dead and down timber, a waste product called "lightwood." The live or green wood is not so suitable for this manufacture, owing to the moisture content and also to the fact that the bark still remains. Stumps, however, are very valuable, as they contain a much larger proport on of resins than "lightwood." Nevertheless, the cost per cord of stump wood is considerably more. as the stumps usually require the additional expense of removal by explosives. The cost per cord of "lightwood" at the works will run from $2.00 to $3.00, making, however, no allowance for its value as waste; while stump wood will vary from $3.50 to $5.00 per cord, the price depending on acre stumpage and hauling distances. The manufacture may be divided into five general processes; steam process, solvent process, alkali process, bath process and distillation process.

Before entering into a description of these various methods we desire to emphasize the statement that the manufacture of wood turpentine necessarily will become of far-reaching importance in the future. This is for the reasons that it is utilizing an absolutely waste product and is at the same time clearing cut-over lands and rendering them fit for occupancy. We wish also to emphasize the statement already made that many past failures were due to the unreasonable speculative condition of the markets. Abnormally high prices of naval stores induced promoters and unscrupulous persons to capitalize their concerns on the earning capacity during this period, thereby making them "stock jobbing" propositions rather than legitimate manufacturing institutions. This kind of financing while apparently expanding the industry really retarded development, as the energies of the management were expended primarily in the office and at the expense of the manufacturing organization.

We have seen from time to time figures of promoters, regarding yields and manufacturing costs of the different processes, which are not in accord with the results obtained from continuous operations. It may not be entirely without value therefore to cite some comparative yields and operation costs in these different processes, especially since there does not appear to be any published data of this nature. While the records themselves of individual plants would be interesting, such records are often misleading and in view of actual or possible competition, the location of plants must be withheld.

In submitting data as to yields, values and productive costs,

we have complied them mainly from the actual results obtained during continued operation of a number of large plants. As so many elements making up these figures are variable, owing to location, construction and raw material, our endeavor has been to average them so that a comprehensive idea may be had as to actual results obtained commercially.

STEAM PROCESS

This process was the first to be extensively placed in commercial operation, and is very simple in its construction and handling. It consists merely of "hogging" the wood and placing it in a steel cylinder, holding usually about a cord, distillation being carried on with live steam and under varying pressure. However, there probably was little difference in results whether a maximum of five pounds or twenty pounds pressure was used. Distillation was carried forward until oils ceased to be obtained in quantity.

It should be borne in mind that there is a decided variance in the resinous content of wood; therefore, it was quite possible to make a selection that would run as high as 30 gallons of turpentine to the cord. We believe the following figures, however, based on a cord of long leaf yellow pine lightwood, weighing 3500 pounds, would be the average.

The fuel cost is only the labor of handling the treated chips. However, there is no allowance made for the office, upkeep, depreciation, insurance, etc. Therefore, it can be seen that the steam process, in order to be profitable, necessarily demands a market price considerably in advance of the present markets.

The price of Wood Turpentine is always a few cents per gallon under that of Gum Turpentine. The quality of the product

Turpentine—9 1/2 gals. at 35 cents	$3.32
Pine Oil—3 gals. at 35 cents	1.05
Total value of products	$4.37

Production Cost Per Cord

Wood	$3.00
Labor	1.00
Barrels	0.42
Freight (approximate)	0.20
Selling Commission	0.25
	$4.87

produced by the steam process, however, is excellent. Our opinion is, nevertheless, that at least 50 cents per gallon is necessary as a minimum for successful operation.

SOLVENT PROCESS

In the early development of this process the wood was subjected to the old steam treatment and subsequently treated with carbon disulfide for the recovery of rosin. The loss of solvent rendered it impractical. In the next stage of development the wood was hogged and placed in digestors for the recovery of turpentine and pine oil. Then the solvent (a low grade of gasoline) was added, live steam was applied recovering some turpentine, pine oil, and solvent by distillation and the

dissolved rosin drawn off, its volatile matter being recovered by distillation. This has been improved, in some instances, by omitting preliminary steaming, adding solvent direct and recovering this with the turpentine and pine oil by live steam in the primary distillation, obtaining rosin alone when the still is drawn. The rosin, however, is soft, and difficulty has been experienced in obtaining a hard product, but this is overcome by subsequent treatment. In either method a considerable loss of solvent is always entailed, varying from 17 to 30 gallons per cord. The approximate yields and operating costs per cord are as follows:

Turpentine—9½ gals. at 35 cents	$3.32
Rosin—400 lbs. at $4.00 per 280 lbs.	5.72
Pine Oil—3 gals. at 35 cents	1.05
	$10.09

Production Costs per Cord

Wood	$3.00
Labor	2.50
Loss in solvent at 15 cents (17 gals.)	2.55
Barrels	.42
Rosin Barrels	.25
Selling Costs	.50
Freight	.75
Total	$9.97

Again the actual fuel cost in this process is negligible as use is made of the "treated chips." No allowance is made here for insurance, upkeep, overhead and interest charges, refining costs or depreciation; therefore, it is plainly evident that, at present market prices, at least until improvement is made in yields or in minimizing costs, there is not sufficient margin for successful operation. However, it is quite possible that by using the "treated chips" for paper pulp manufacture this process can be made of commercial value. The operation in this case would have to be maintained on an enormous scale in order to supply treated chips for a pulp plant unit of an economic size. A plant using this solvent system and built on a very elaborate scale, was in operation in southeastern Georgia, and, despite the most advantageous financial backing, was unable to operate profitably on a weakened market, and is now in the hands of receivers. This citation alone probably would not necessarily condemn the process, but as several smaller plants are either in like position or shut down, it indicates the necessity of research or development if ultimate success is to be attained. As with the steam process, many claims of higher yields than we have above credited are made by interested parties, but these claims are still subject to substantiation.

ALKALI PROCESS

This process is essentially one to be applied to the alkali processes for manufacturing paper pulp from resinous woods with the recovery of turpentine and rosin and at the same time improving the quality of the pulp, and promoting ease of manufacture. The process is well covered by patents.

The basis upon which this method rests is the fact that the

sodium hydroxide saponifies the resins in the wood and the sodium resinate thus formed may be separated from the spent soda pulp liquor by temperature regulation. The wood is handled in the same manner as in soda pulp manufacture, except that after digestion the spent liquor is cooled for the separation of sodium resinate before the liquor proceeds to the evaporators. This product has been so purified and refined, commercially, as to produce a good quality of paper size. The resinate may if desired be manufactured into resin by acid treatment, or destructively distilled to produce rosin oils. The turpentine is recovered from the digester blow-off during the digestion operation. This process is apparently theoretically sound, but requires the outlay of capital to develop thoroughly the mechanical details. Fifty to seventy thousand dollars were expended in one case to demonstrate its commercial possibilities and some results were obtained. However, the enterprise has not been financially successful and the plant has been dismantled, a fact which may be due to faulty engineering or other causes; and even though the process appears enticing from a theoretical viewpoint the fact remains that the trial was not successful and there is no process of this kind in actual operation. Nevertheless, it is our opinion that eventually it will be of commercial importance and ultimately the combination of the two industries, paper pulp and turpentine-rosin recovery, thus utilizing resinous wood, will be successful. Unusual yields of turpentine are claimed by a Florida plant using an alkali bath but satisfactory arrangements have not yet been made regarding rosin recovery

BATH PROCESS

This process must not be confounded with the recently suggested process using a bath or envelope of oil external to the oven for the purpose of heating the same. This external bath process has not been long enough in operation to demonstrate its future and it will be interesting to note whether certain fundamental operation difficulties can be overcome.

By Bath Process we refer to the process commercially so called which has been in operation for some time and in which the bath is *within the oven* or retort in contact with the wood itself. Three plants using this method have been built, the first in North Carolina, which has been dismantled, the others at Mt. Pleasant, Georgia, and Jacksonville, Florida, which have not been successful owing to low market conditions and both of which have gone into receivers' hands within the last few months.

The process itself was divided into two separate general operations: first, the recovery of turpentine and pine oil, or "sweet spirits," and subsequently the destructive distillation of the wood itself, although this second operation was not contemplated in the original process.

The operation has a decided advantage over the solvent and steam processes in that it does not require the "hogging" of the wood.

The general construction used in this first operation consists of steel cylinders at Mt. Pleasant, and concrete ovens at the Jacksonville plant, each holding five to nine, one or two cord

steel cars, similar in construction to those in common use in hard wood distillation; thus each oven holds about nine cords of wood. Placed at the side of the oven is a heater equipped with a large cast iron worm joined to the bottom of the oven. To the rear of the heater is placed a large steel or concrete reservoir connected by cast iron pipe with the top of the oven, and also with rotary pumps which in turn are joined to the heater pipes.

The loaded cars are placed in the oven and melted rosin or pitch is run into the reservoir and circulated by the pumps through the heater and the bottom oven connection. This pitch after filling the oven *in contact with the wood* overflows into the reservoir and is thus continually circulated through the heater and oven, thereby vaporizing the volatile resinous bodies, without dissociating the wood fiber. The turpentine and oil vapors are carried through a "vapor" chamber in which the high boiling liquids that are mechanically carried by the vapor are separated, the vapor continuing to an ordinary tubular condenser, where the crude "sweet spirits" are obtained. Afterwards the "sweet spirits" are refined, the products being turpentine, pine oil and a tarry residue. The time required to treat a charge varies in the plants mentioned from seven to ten hours, and the product obtained is of high quality, though not so good as steam process turpentine.

At first sight it would appear that in this process the rosin from the wood treated would gradually increase the volume of the bath and rosin be thus manufactured. The reverse of this, however, is the case, as a serious loss of bath is actually realized. This is in fact a very serious drawback to the process, and is probably due to the formation of volatile rosin oils when the liquid bath encounters the high temperature of the heater. These rosin oils are volatilized and pass into the "crude spirits," and are lost in the refining residue, as only from 65 to 70 per cent of the spirits is received as turpentine and pine oil. By proper arrangement this difficulty could be avoided.

This process is also seriously handicapped by the fuel consumption of the heaters and the heavy upkeep for heater pipes and pumps. Nevertheless, with proper design, operation costs would be much reduced from that actually experienced.

After refining, the results from this "sweet process" could be averaged as follows:

Turpentine, 7½ gals. at 35 cents....................	$2.62
Pine Oil, 2.5 gals. at 35 cents........................	.87
	$3.49

After the charge is withdrawn in this first operation the "treated" wood is placed in ovens similar to those used in the hard wood industry and there subjected to destructive distillation. The results obtained here are very important as a good market has been created for these products. An average of from 68 to 70 gallons of oils is obtained, together with a like volume of "acid water," the latter a "waste," although its utilization was accomplished just prior to the receivership of one of the

mentioned companies. In addition there remains in the cars approximately 900 pounds of charcoal and there is produced about 10,000 feet of non-condensible gas per cord which is of fuel value.

This crude distillate above mentioned is called "destructive distillate" or "D. D. Product" to distinguish it from the product derived from the resins, called "sweet spirits." On refining there are obtained the following products per cord:

Tar, 41 gals. at $.08	$3.28
Light Oil, 6.8 gals. at $.12	.81
Heavy Oil, 10 gals. at $.12	1.20
Charcoal, 36 bushels at $.075	2.70
From "sweet process"	3.49
Total	$11.48

Costs of Production per Cord

Wood	$ 3.00
Fuel	3.25
Labor	2.75
Cooperage	1.00
Selling Costs	.60
Freights (approximate)	.75
	$11.35

Again it can be seen that this process handled as it has been in the past cannot be operated successfully on a low market, as no allowances have been made for upkeep, insurance, interest charges, refining costs, management or depreciation. Although the loss in bath is partially made up by the pitch obtained, it can be seen from these costs that improvement must be had before this process can exist during low market conditions. It is not to be inferred, however, that the principles upon which the process is based are entirely faulty. The reasons for its failure appeared to be lack of knowledge as to the chemical nature of the products and troubles consequent to improper construction and operation. As is common with approaching dissolution strenuous efforts at improvements were made in this process, and despite well known prior failures, experiments were completed and operation commenced for the utilization of the waste "acid water" just before the closing of one of the plants. The results proved interesting and promised excellent recovery, as the products recovered, including acetate of lime and wood alcohol, represented a net gain of well over $1.50 per cord.

DISTILLATION PROCESS

As the wood turpentine industry now stands, the destructive distillation process apparently has the best chance of commercial success, as it is not only more simple in construction and operation, but yields more in volume of products. Chemical and engineering skill, nevertheless, are necessary for this success.

The distillation process may be subdivided into three divisions: *first*, that division analogous to hard wood distillation. This method in its primary operation is very similar in equipment and design to the usual hard wood distillation plant, the wood being placed in steel cars and run into ovens. The products derived

from the resins and those from the dissociated wood are collected together, and separation is made during refining, although some attempt has been made at fractional distillation in this primary stage. This method gives a much inferior grade of turpentine, etc., owing to the commercial difficulty of eliminating the pyroligneous bodies, and the product will not answer to the permanganate test which indicates pyroligneous matter. The tar produced in this operation is usually resinous and for some uses, therefore, objectionable.

The *second* division is merely a modification of this process, the ovens being in duplicate, and distillation for the resinous bodies being carried out in one oven, so designed or "set" that the temperature can be maintained approximately uniform. After the resinous bodies have been obtained the "treated wood" is withdrawn and placed in a second oven and in this oven the distillation is carried at a higher temperature for the destructive distillation of the wood itself.

The *third* division is that using concrete ovens containing 12 inch heater pipes running the length of the ovens. These ovens have dutch-oven connections and the flue gases travel through these pipes, and it is claimed that temperature regulation is more easily accomplished.

In all these processes the products obtained are the same, except so far as the degree of purity is concerned.

The first distillate, or that from the resins in these methods, will run on an average 22 to 24 gallons of "sweet spirits." This on refining will give from 50 to 60 per cent or from 12 to 14 gallons of marketable turpentine and from 9 to 10 per cent or from 2 to $2^1/_2$ gallons of pine oil, and also 100 pounds of a very resinous pitch.

The destructive products are the same as those from the "bath process;" thus it can be seen that the gross total in this operation should be materially higher than in the other processes, while the operating expense is very much lower. This, including wood, upkeep, and in fact all expense, should not, under proper design, construction and management, run over $9.00 a cord.

The particular objection raised against the destructive distillation process is that the products are difficult to market, and this has been true to a certain extent in the past, but when it is considered that many of these products were new to the trade this condition cannot be wondered at, and at present the marketing is not more difficult than products of other processes. In fact, just now there is an unusual demand for these products.

MARKETS

It may, perhaps, be of interest to call attention to the various developed markets for the D. D. Products, for we all realize that the marketing of products is at least equal in importance to the manufacture; and this industry shows many instances where comparative merit of process and operation was wholly lost by inferior marketing facilities, and, on the other hand, instances in which unsound operation was maintained for a considerable time by a remarkably efficient selling organization. The latter

cases, while losing ventures to those financially interested, have no doubt succeeded in creating a growing demand for the products, as indicated by the prices now obtained for them, with many plants closed down. At the present time tar could be easily sold for 12 cents per gallon as compared with the 8 cents allowed in the cost data in this article, but which should be considered maximum, as the future will undoubtedly increase supplies so as to bring these prices back to a more nearly normal condition. This fact, however, does show that a demand has been created that did not exist prior to the quite recent establishment of plants of this nature. Perhaps this condition is more clearly evidenced in the heavy D. D. oil, for which 22 cents per gallon is being obtained. The tar demand had in a measure been previously supplied by that known as "kiln tar" made at works using the kiln system for charcoal manufacture from resinous woods.

The product mentioned as D. D. light oil is at present most difficult to market profitably. It is on the market in this form and is used to some extent by manufacturers of disinfectants. However, it has been fractionally distilled and has been used locally as a substitute for gasoline for use in engines and has proven itself to be more efficient than gasoline. The comparatively small amount of this product makes its use in this manner merely of local interest but it indicates a real value of the product.

The heavy D. D. oil has been in consistent and increasing demand, particularly in the paint industry, and notably for shingle stains; also for the manufacture of tar oils for which there is a large foreign demand. The necessity of an energetic market agency for this product was in one case well illustrated within the past year. One large concern, having nearly 100,000 gallons in storage, and finding it impossible to market, was offering it for 5 cents per gallon, while at the same time another company was unable to supply its customers at 18 cents per gallon. Of course, the latter considered the purchase from the former, but feared future competition in case, as seemed dangerously probable, the former concern should learn of their customers.

The pitch produced in the distillation process and distinguished from the tar has a firm market demand from ship chandlers and also is sold for uses such as coating silos, rendering them impervious to moisture.

The tar, of course, has its established used with rope manufacturers as well as with paint producers, while the charcoal consumption, particularly in the south, is very steady both for domestic use and manufacturing. Of the number of suggested specialties based on the use of tars and oils, doubtless a few will ultimately contribute a steady demand for a portion of these products.

COSTS OF INSTALLATIONS

The various processes have in most instances exceeded reasonable installation costs. Undoubtedly the same is true in any newly established industry, and more particularly in cases where,

as pointed out in this one, prices could be obtained that were out of all proportion to production costs.

The entire equipment of a steam process plant should come well within $750.00 per cord capacity, while the solvent process complete should be approximately $2,000.00 per cord. This also should be approximately that of the bath system, while the destructive distillation method ought to be very close to $1500. In making these general estimates neither working capital nor purchase of timber or stumpage is considered.

CONCLUSION

When your attention is brought to the fact that the destructive distillation plants alone have been able to survive recent price depression, it is reasonable to conclude that, in the present state of the art, this method has inherent advantages. Nevertheless, in this type of process there is room for much improvement, particularly in refining and the utilization of waste products that were ignored in the past. Constructive chemical engineering in this industry apparently has opportunity to create an unusually profitable business, provided it utilizes the unfortunate mistakes of the past, by combining parts of the various processes.

It is not to be inferred from this article that recommendations are made for the encouragement of any particular process. The motive is merely to outline present conditions or, broadly, to show cause and effect; and also to show, if possible, that in order to attain success, many elements are as necessary in this industry as in any other. Statements have been made to the effect that failures in most instances were due to lack of real engineering skill, and this is partly true, but lack of skill is not wholly accountable for even the engineering failures, as no amount of theoretical engineering skill can replace the knowledge acquired from continued intimate contact with the going operation.

Neither does this statement take into consideration the marketing organization, which is also an essential, and is always confronted with the general economic situation, although this does not affect directly the operation.

It can be seen from this outline of the industry that its very existence was primarily due to an unnatural market condition, and as the field for profit and exploitation was so enormous it can hardly be wondered at that there was unusual activity in its promotion.

Ohio State University, Columbus

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The Ohio Coal Supply and Its Exhaustion

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The Ohio Coal Supply and Its Exhaustion

INTRODUCTION.

The importance of **coal** in modern civilization cannot be overestimated. It offers to mankind **solar energy** in its most concentrated form. It is the father of modern civilization. The great coal producing nations of the world which have been developed by its use, viz., the United States, Great Britain, Germany, France, Austro-Hungary, Belgium, Russia, and Japan, are the greatest commercial nations. The fires of industry and the centers of population in these countries cluster around their coal supplies. This supply is definite, and it is not inexhaustible. Every ton of it taken out of the earth, or lost in mining, or wasted in using leaves just that much less for the future needs of the world.

The use of coal as a fuel began within the last hundred years. Its production in the United States in 1850 was 7,000,000 tons, and in 1912 it was 696,000,000 tons. The Ohio production in 1850 was 704,000 tons and 62 years later it was 34,000,000 tons, or nearly 50 times as great.

With such enormous increases in the consumption of coal, the question of the future supply must give concern to all thoughtful men.

The world's supply of coal has not yet been measured. It is doubtful if even the oldest and most civilized of the nations know the amount of their coal supply. Many years of careful exploration are yet needed to define the coal areas in all parts of the world.

Mr. Marius R. Campbell in "The Coal Resources of the World" estimates the original tonnage of the United States at 3,225,394,200,000 tons, and the total production to 1912 at 11,926,140,000 tons, leaving a reserve of 3,213,468,000,000 tons; to which may be added Brook's and Martin's estimate of Alaska, amounting to 19,593,000,000 tons, or a total of 3,233,060,800,000 tons as the coal reserve of the United States and Alaska.

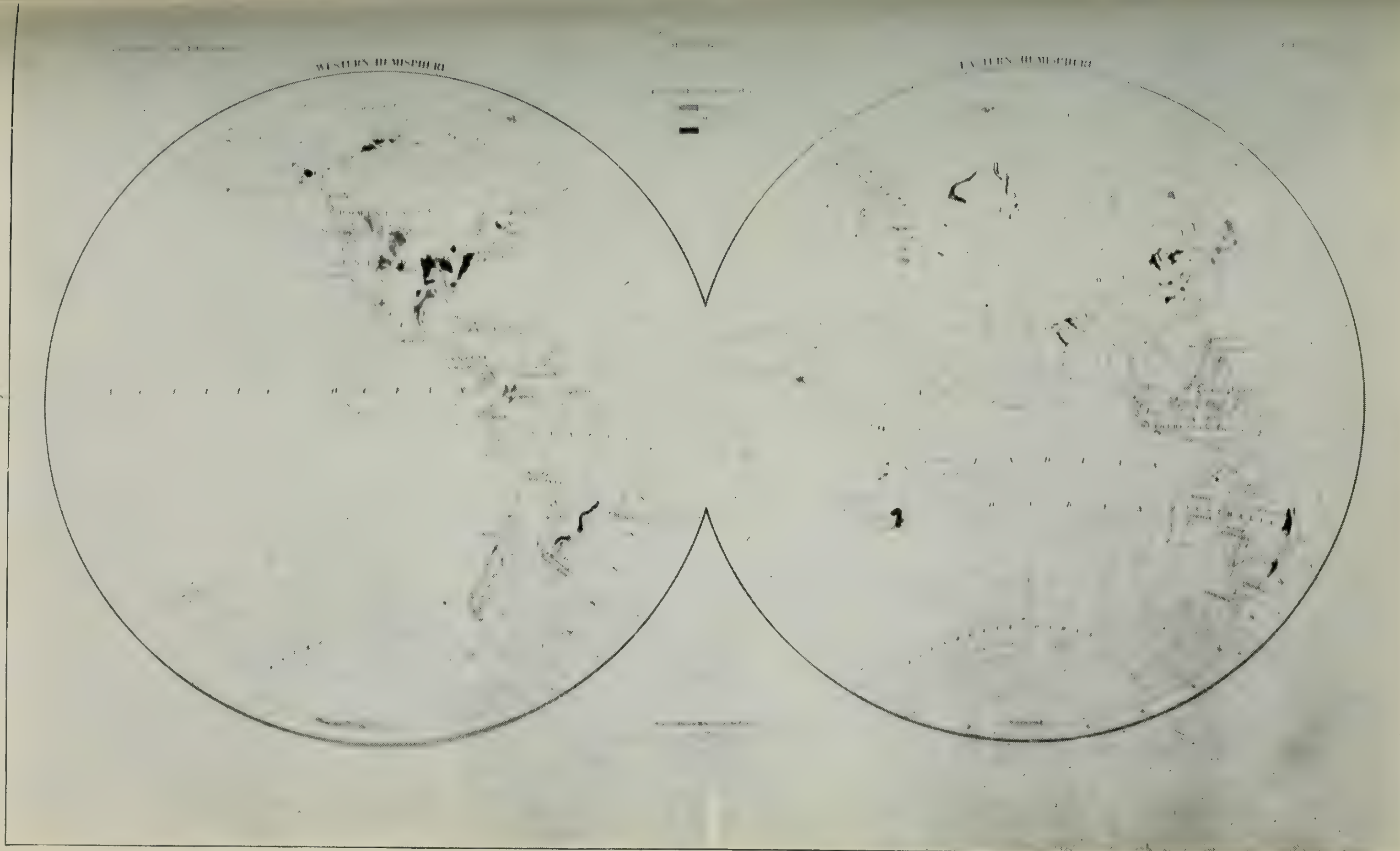
Mr. Campbell estimates the original tonnage of Ohio coals at 85,000,000,000 tons. The total production to 1912, including the estimated losses in mining, amounts to 926,667,000 tons. This would leave a coal reserve for Ohio of about 84 billion tons, which means the equivalent of a continuous coal seam 7 feet thick over the entire area of Ohio coal measures.

The writer hopes to show that such published estimates of the coal reserves at this time cannot be even approximately correct because of our meager knowledge of the coal seams on which all such estimates of coal reserves must be based.

THE COAL FIELDS OF THE WORLD

In late years our attention has been called by our law-makers to the question of coal reserves, not only for our own State and Nation, but of the world as well. The very large increase in the consumption of coal in recent years makes this a question of grave importance.

Map Page 5 has been taken from "The Coal Resources of the World," and shows the location of the world's coal supply. It will be noted that the greater part lies in the Northern Hemisphere. This is said to be due partly to the larger land areas found there, and partly to the fact that the earlier coal-bearing portions of the carboniferous strata are not represnted in the Southern Hemisphere. The writer is proud to be able to call attention to the fact that our country possesses over one-half of the estimated coal reserves of the world.



The Coal Areas of the World. (Indicated by the black spots.)

ESTIMATE OF THE COAL RESERVES OF THE WORLD IN MILLION TONS.

(See Map, Page 5.

Country.	Class A Anthracite Including Some Dry Coals.	Classes B and C Bituminous Coal.	Class D Sub-bituminous Brown Coals and Lignites.	Totals.
Oceana	659	133,481	36,270	170,410
Asia	407,637	760,098	111,851	1,279,586
Africa	11,662	45,123	1,054	57,839
Newfoundland	....	500	....	500
Canada	2,158	283,661	948,450	1,234,269
Central America	....	1	4	5
South America	700	31,397	....	32,097
Europe	54,346	693,162	36,682	784,190
United States	19,684	1,955,521	1,863,452	3,838,657
Total	496,846	3,902,944	2,997,762	7,397,553

CLASSES A, B, C, AND D BRIEFLY DEFINED.

Class A. Includes coal that burns with short, blue flame, or with slightly luminous, short flame and little smoke; does not coke and yields from 3 to 5 per cent combustible matter. Fuel ratio, 7 to 12 or over. Calorific value, 8000 to 8060 calories.

Class B. Burns with short, luminous flame and yields 12 to 15 per cent volatile matter; does not readily coke. Fuel ratio, 4 to 7. Calorific value, 8400 to 8900 calories.

Or burns with luminous flame and yields from 12 to 26 per cent volatile matter; generally cokes. Fuel ratio, 1.2 to 7; Calorific value, 7700 to 8800 calories.

Or burns freely with long flame, which stands weathering but fractures readily, and occasionally contains moisture up to 6 per cent. Makes porous coke. Fuel ratio, 2.5 to 3.3. Calorific value, 6600 to 7800 calories.

Class C. Burns with long, smoky flame; yields from 30 to 40 per cent volatile matter on distillation, leaving a very porous coke. Fracture generally resinous. Calorific value, 6600 to 880 calories.

Class D. Contains generally over 6 per cent of moisture; disintegrates on drying; streak brown or yellow; cleavage indistinct; moisture in fresh-mined, commercial output up to 20 per cent; fracture generally conchoidal; earthy and dull; drying-cracks irregular, curved lines. Calorific value, 5500 to 7200 calories, or moisture in commercial output over 20 per cent. Calorific value, 4000 to 6000 calories.

(Taken from "The Coal Resources of the World," Vol. 1, Page X to XIII, inclusive.)

THE COAL FIELDS OF THE UNITED STATES.

(See Map, Page 8.)

There are seven general coal areas in the United States.

The Pennsylvania Anthracite Fields cover 480 square miles.

The Appalachian Coal Field covers the coal area in Ohio, Pennsylvania, West Virginia, Virginia, Eastern Kentucky, Tennessee, and Alabama, amounting to an estimated area of 69,485 square miles.

The Interior Fields include the coal of Michigan, Indiana, Western Kentucky, Illinois, Iowa, Missouri, Kansas, Oklahoma, Arkansas, and Texas, amounting to an estimated area of 132,900 square miles.

The Gulf, or Lignite Field includes the lignite coal bordering the Gulf of Mexico, lying in the States of Arkansas and Texas, amounting to an estimated area of 2,100 square miles.

The Rock Mountain Fields include the lignite and bituminous coals of North and South Dakota, Montana, Wyoming, Colorado, New Mexico, Idaho, Utah, Arizona, amounting to 126,022 square miles of known coal fields.

The Pacific Coal Fields include the coal areas of Washington, Oregon, and California, amounting to 1900 square miles. The total bituminous coal embraced by these regions given in "The Coal Resources of the World" amounts to a little less than 340,000 square miles.


COAL FIELDS
OF THE
UNITED STATES
Showing areas of coal bearing formations
School of Mines - Ohio State University
April 29 1904
LEGEND
CANADA
GULF OF MEXICO
PACIFIC OCEAN
ATLANTIC OCEAN
EASTERN INTERIOR
WESTERN INTERIOR
NORTHERN INTERIOR
ROCKY MOUNTAIN FIELDS
NORTH DAKOTA
NEBRASKA
ARIZONA
NEW MEXICO
UTAH
LAKE ERIE
LAKE HURON
LAKE MICHIGAN
LAKE SUPERIOR
10

ESTIMATE OF ORIGINAL TONNAGE OF COAL IN THE UNITED STATES.

BY MARIUS R. CAMPBELL.

Province, State, and Field.	Areas in Square Miles.			Estimated.		Original Amount of Coal in Metric Tons.				
	Known Coal Field.	Possible Coal Field.	Coal below a Depth of 3,000 Feet.	Lignite (No. 2, Class D.)	Subbituminous Coal (No. 1, Class D.)	Bituminous Coal (Class C and No. 2, Class B.)	Semibituminous Coal (No. 1, Class B.)	Anthracite and Semianthracite Coal. (Class A.)	Coal below surface from 3,000 to 6,000 Feet.	Total production of coal to end of 1910.*
Eastern Province—										
Penna.										
Anthracite region	480							19,056,300,000		1,978,525,100
Bituminous field	14,200					93,080,000,000	9,074,000,000			2,043,319,940
Ohio	12,660					85,270,000,000				527,395,010
Maryland	455					1,368,000,000	5,932,000,000			146,301,270
West Virginia	17,000					111,293,500,000	27,132,000,000			535,042,310
Kentucky	10,270					61,513,000,000				See below
Virginia										66,014,890
Southwestern fields	1,550					18,829,400,000	227,000,000			
Brushy Mt. fields	200							*817,000,000		
Atlantic Coast region	150					544,000,000				
North Carolina	60					181,500,000				432,670
Tennessee	4,400					23,289,500,000				94,359,160
Georgia	167					846,600,000				7,964,570
Alabama										187,072,430
Warrior and Plateau fields	7,845					57,634,600,000				
Cahaba field	268	82	*			3,421,000,000				
Coosa field	260					272,000,000				
	69,965	82				457,543,100,000	42,365,000,000	19,873,300,000		
Interior Province—										
Michigan	11,000					10,889,300,000				17,239,220
Indiana	6,500					48,140,700,000				186,006,680
Kentucky	4,900	1,500				50,400,000,000				143,350,120
Illinois	35,600					182,758,400,000				717,180,790
Iowa	12,560					26,461,000,000				149,234,110
Missouri	23,960					76,225,000,000				97,706,150
Kansas	18,600					27,223,200,000				99,210,200
Oklahoma	10,000					49,865,200,000				44,064,190
Arkansas	1,580					154,000,000	1,112,800,000	*363,000,000		27,330,060
Texas	8,200	5,300				7,259,500,000				18,200,490
	132,900	6,800				479,377,200,000	1,112,800,000	363,000,000		

*Probably exceeds 3,000 in depth.

*Parker, E. W. Mineral Res. of U. S. for 1910. *Semianthracite.

ESTIMATE OF ORIGINAL TONNAGE OF COAL IN THE UNITED STATES—Continued.

Province, State, and Field.	Areas in Square Miles. Known Coal Field.	Possible Coal Field.	Coal below a Depth of 3,000 Feet.	Estimated. Original Amount of Coal in Metric Tons. Lignite (No. 2, Class D.)	Subbituminous Coal (No. 1, Class D.)	Bituminous Coal (Class C and No. 2, Class B.)	Semibituminous Coal (No. 1, Class B.)	Anthracite and Semianthracite Coal. (Class A.)	Coal below surface from 3,000 to 6,000 feet.	Total production of coal to end of 1910.
Gulf Province—										
Arkansas	100	5,900		81,700,000						See above
Texas	2,000	53,000		20,871,000,000						See above
Northern Great Plains										
Province	2,100	58,900		20,952,700,000						
North Dakota	29,630	6,350		633,329,800,000						3,562,690
South Dakota	2,160	8,820		925,900,000						See below
Montana—										See below
Fort Union region	33,132			331,646,700,000	4,353,100,000					
Bull Mt. field	633	457			2,722,300,000					
Assiniboine region	3,000					1,814,900,000				
Judith Basin region	1,500									See below
Wyoming						120,700,000				
Black Hills region	320				124,750,500,000					
Powder River region	10,800	3,200								131,573,490
Colorado					36,297,700,000					
Denver region	5,380	1,480				932,800,000				
Canon City field	40					22,198,000,000				
Trinidad field	1,035		80							28,223,970
New Mexico						16,270,400,000				
Raton field	960									
Rocky Mt. Province—	88,590	20,307	80	965,902,400,000	168,123,600,000	41,336,800,000				
Montana										29,160,000
N. F. Flat Head Rv. field										
Mountain fields	150				3,081,700,000					
Yellowstone region	10	100			90,700,000					
Red Lodge-Bridger	50					42,900,000				
field	50	450			1,535,200,000	552,500,000				4,040
Idaho					90,700,000					
Goose Creek field	30					544,500,000				
St. Anthony field	200	1,000								88,234,900

ESTIMATE OF ORIGINAL TONNAGE OF COAL IN THE UNITED STATES—Continued.

Province, State, and Field.	Areas in Square Miles. Known Coal Field.	Possible Coal Field.	Coal below a Depth of 3,000 Feet.	Estimated. Lignite (No. 2, Class D.)	Original Amount of Coal in Metric Tons. Subbituminous Coal (No. 1, Class D.)	Bituminous Coal (Class C and No. 2, Class B.)	Semibituminous Coal (No. 1, Class B.)	Anthracite and Semianthracite Coal. (Class A.)	Coal below surface from 3,000 to 6,000 feet.	Total production of coal to end of 1910.
Wyoming					907,400,000				1,800,000,000	
Bighorn Basin region	905	430	2,830		1,828,600,000				9,100,000,000	
Hanna field	160		3,340		20,871,000,000	9,074,400,000				
Green Rv. Basin reg.	1,435	240			370,472,000,000	57,196,200,000			180,000,000,000	
Wind Rv. Basin reg.	6,440	870	9,970		16,706,000,000	6,715,100,000				
Hams Fork region	600									
Colorado										See above
North Park field	57	43			2,588,600,000					
Yampa field	3,130				37,954,000,000	85,025,300,000		20,500,000	180,000,000,000	
Unita Basin region	2,780		3,720			75,847,500,000		435,900,000	130,000,000,000	
South Park field	3	70				18,100,000				
Durango field	1,840	20			17,693,300,000	8,504,500,000				
Tongue Mesa field	40					842,300,000				
S. W. Colorado field	36					74,000,000				
Utah										23,111,320
Uinta Basin region	3,276		7,530			76,392,000,000			91,000,000,000	
Coalville field	20				141,700,000					
Colob Plateau field	350					*3,629,800,000				
New Mexico—										
San Juan R. region	10,700		1,000		150,778,000,000				13,000,000,000	
Small fields	1,560				6,125,000,000	903,300,000		7,200,000		
Arizonaa—										
Black Mesa field	3,580				12,776,800,000					
Small fields	30				55,700,000	9,100,000				
	37,432	3,223	28,390		643,696,400,000	325,371,500,000		463,600,000		

*Includes some impure anthracite.

ESTIMATE OF ORIGINAL TONNAGE OF COAL IN THE UNITED STATES—Concluded.

Province, State, and Field.	Areas in Square Miles Estimated.			Original Amount of Coal in Metric Tons.						
	Known Coal Field.	Possible Coal	Coal below a Depth of 3,000 Feet.	Lignite (No. 2, Class D.)	Sub-bituminous Coal (No. 1, Class D.)	Bituminous Coal Class C and No. 2, Class B.)	Semi-bituminous Coal (No. 1, Class B.)	Anthracite and Semi-anthracite Coal, (Class A.)	Coal below surface from 3,000 to 6,000 Feet.	Total production of coal to end of 1910
Pacific Coast Province.										
Washington	1,800	....	....	....	47,588,800,000	10,355,700,000	....	21,100,000	....	48,682,210
Oregon	90	140	....	....	907,400,000	....	....	....	....	1,843,430
California	10	30	....	....	14,900,000	25,000,000	....	....	....	4,634,030
	1,900	170	....	....	48,511,100,000	10,380,700,000	....	21,100,000	....	*35,374,600
Grand Totals........	339,887	89,482	28,470	986,855,100,000	860,331,100,000	1,314,009,300,000	43,477,800,000	20,721,000,000	‡604,900,000,000	7,480,355,040
Fifty per cent. added for waste..........	....	....	....	....	....	....	....	....	....	3,740,177,520
Estimated amount exhausted	....	....	....	....	....	....	....	....	....	11,220,532,560
	....	....	....	986,855,100,000	....	....	....	....	....	....
	....	....	....	860,331,100,000	....	....	....	....	....	....
	....	....	....	1,314,009,300,000	....	....	....	....	....	....
	....	....	....	43,477,800,000	....	....	....	....	....	....
	....	....	....	20,721,000,000	....	....	....	....	....	....
Total of all kinds of coal except‡	....	....	....	3,225,394,300,000	....	....	....	....	....	....

*Colliery consumption, etc.

‡Parker, E. W. Mineral es. of U. S. for 1910.

TOTAL RUN OF MINE COAL PRODUCED IN OHIO.

BY YEARS FROM 1828 to 1882, INCLUSIVE.

Year	Tons	Year	Tons	Year	Tons	Year	Tons
1828	20,900	1842	247,500	1856	1,023,000	1870	2,780,113
1829	31,900	1843	308,000	1857	1,525,000	1871	4,400,000
1830	42,900	1844	374,000	1858	1,100,000	1872	5,846,794
1831	53,900	1845	429,000	1859	1,166,000	1873	5,005,028
1832	64,900	1846	462,000	1860	1,392,100	1874	3,594,285
1833	75,900	1847	528,000	1861	1,265,000	1875	5,350,259
1834	86,900	1848	594,000	1862	1,320,000	1876	3,850,000
1835	97,900	1849	660,000	1863	1,324,951	1877	5,775,000
1836	108,900	1850	704,000	1864	1,996,562	1878	6,050,000
1837	119,900	1851	537,000	1865	1,689,839	1879	6,600,000
1838	131,852	1852	770,000	1866	2,076,166	1880	6,716,595
1839	137,500	1853	836,000	1867	2,301,567	1881	10,164,000
1840	159,860	1854	880,000	1868	2,723,428	1882	10,395,000
1841	176,000	1855	979,000	1869	2,708,184	Total	109,956,583

Note:—Years 1828 to 1839, inclusive, interpolated by F. A. Ray.

Years 1840 to 1882, inclusive, taken from Mineral Resources.

Vol. 2, 1908—Tonnage as given in Mineral Resources is for lump and nut coal to which F A. Ray has added 10% for slack coal.

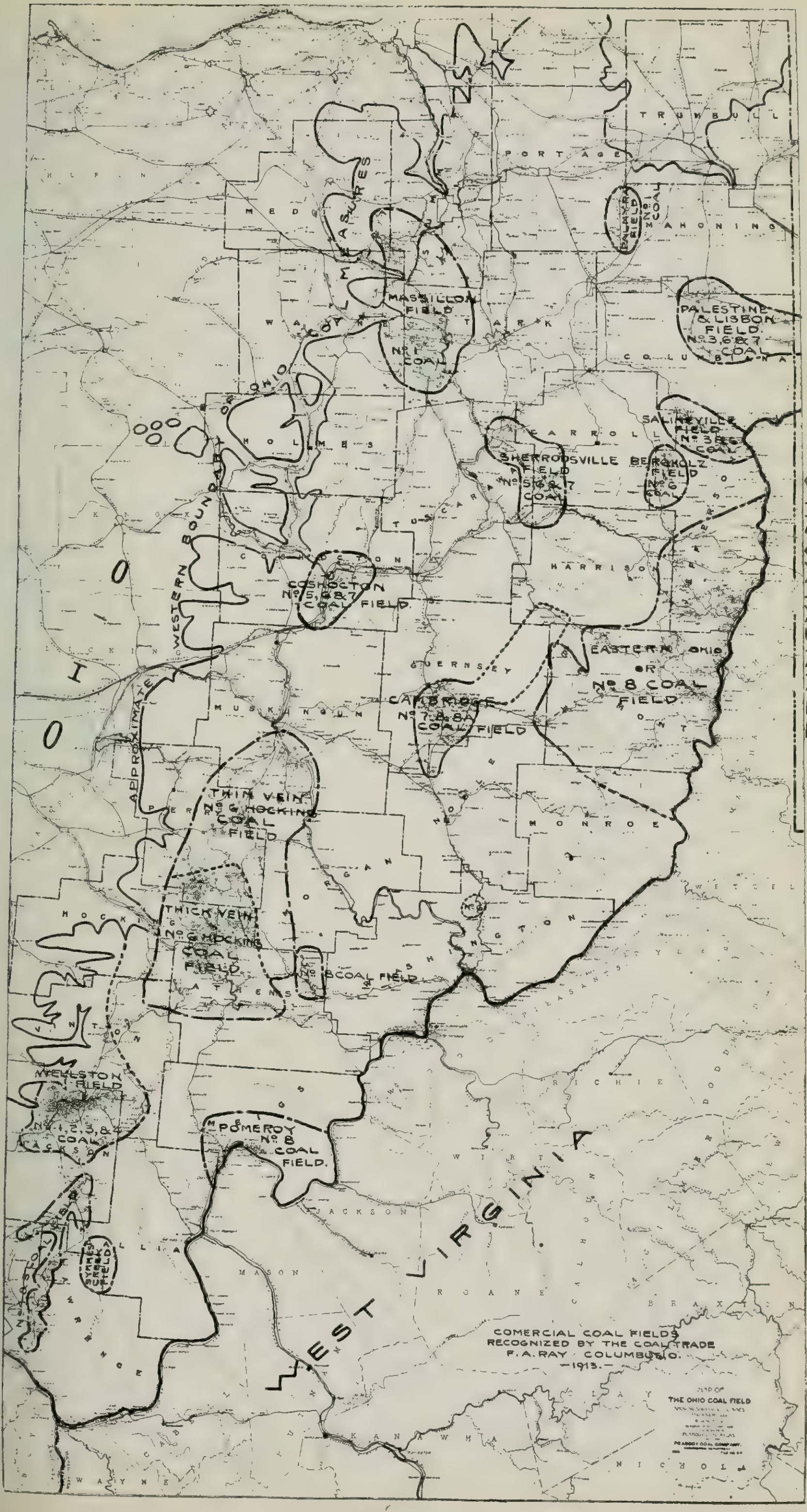
The area of Ohio coal measures amounts to 11,396 square miles, or about one-thirteenth of the coal area of the United States. It must be remembered that these figures are merely estimates, and in the younger states may not be even approximately true.

Alaska is credited with having an area of 1,200 square miles of known coal and 16,000 square miles of possible coal fields. We are liable to find such estimates very misleading approximations.

Name of Counties.	1883	1884	1885	1886	1887	1888	1889	1890	1891	1892	1893	1894	1895	1896	1897	1898	1899
Athens	915,515	627,944	823,139	899,046	1,083,543	1,336,698	1,466,328	1,420,280	1,374,320	1,590,507	1,622,851	1,457,579	1,435,744	1,383,709	1,299,454	1.533.155	[illegible]
Belmont	622,326	643,129	744,446	533,779	721,767	1,108,106	814,699	827,568	1,259,570	1,249,423	1,277,540	1,193,329	961,367	1,082,964	905,378	1.168.567	[illegible]
Carroll	188,615	102,531	150,695	216,630	293,328	355,092	430,995	420,078	205,521	273,272	290,259	285,180	326,670	278,296	162,537	261.585	[illegible]
Columbiana	622,082	469,708	462,733	336,063	516,057	466,191	628,041	544,851	664,569	610,179	636,608	501,783	644,823	516,005	735.941	896,058	[illegible]
Coshocton	86,300	56,562	99,609	52,934	12,479	167,903	156,341	146,837	205,193	244,149	305,769	181,127	161,723	342,625	326,981	342.604	[illegible]
Gallia	10,956	20,372	16,383	17,426	15,365	16,722	14,868	15,160	18,277	19,634	5,292	13,361	10,341	6,671	15,704	17,391	[illegible]
Guernsey	244,650	375,427	277,267	433,800	553,613	383,728	317,397	547,072	498,859	572,281	534,416	641,561	972,505	1,068,453	861,776	1.176.524	[illegible]
Harrison	......	......	......	5,509	4,032	2,865	1,080	4,792	4,316	8,646	14,698	27,537	26,003	28,391	28,159	[illegible]	[illegible]
Hocking	639,159	372,694	656,441	741,571	853,063	1,086,538	911,488	1,239,576	1,622,429	1,863,303	1,889,996	1,453,391	1,432,741	1,351,511	1,381,414	1.254.74[illegible]	[illegible]
Holmes	26,400	12,052	11,459	12,670	10,526	8,121	10,142	13,358	16,811	16,666	14,181	15,616	12,665	10,164	19,313	15.691	[illegible]
Jackson	490,504	831,720	791,608	856,740	1,135,605	1,088,761	1,257,731	1,291,778	1,598,876	1,770,742	1,778,770	1,499,287	2,072,939	1,651,199	1,649,493	1.804.7[illegible]	[illegible]
Jefferson	221,022	316,777	271,329	275,666	293,875	243,178	294,664	571,909	666,187	879,500	1,138,083	997,888	861,185	670,867	744.790	829.726	[illegible]
Lawrence	170,793	176,412	145,916	166,933	143,559	137,806	111,815	108,505	88,440	127,074	80,741	75,292	125,280	81,746	124.448	68.855	[illegible]
Mahoning	266,371	241,599	275,944	313,040	272,349	231,035	217,118	228,761	232,346	242,515	198,370	97,062	101,866	52,277	92,283	75.149	[illegible]
Medina	316,780	77,160	152,721	252,411	225,487	198,452	132,706	181,861	157,410	220,149	197,405	143,196	265,411	195,669	159,987	147.714	[illegible]
Meigs	397,557	248,436	234,756	192,263	185,205	242,483	228,156	268,599	299,402	308,127	278,562	219,971	216,897	259,296	203,861	193,335	[illegible]
Muskingum	37,400	84,398	86,846	96,601	171,928	211,861	232,298	249,666	232,918	264,473	364,067	248,286	255,230	264,105	339,660	250.718	[illegible]
Noble	......	......	......	3,342	6,320	6,200	14,281	11,565	9,560	9,995	15,360	21,867	19,376	42,507	63,967	62.912	[illegible]
Perry	1,885,199	1,379,100	1,259,592	1,607,666	1,870,841	1,736,805	1,549,450	1,714,762	1,759,790	2,056,896	2,171,495	1,460,831	1,789,109	1,703,816	1,449,178	1.759.890	[illegible]
Portage	79,500	65,647	77,071	70,339	65,163	70,923	65,286	70,687	68,612	87,925	94,586	92,946	87.012	48,060	79,245	75.951	[illegible]
Stark	390,775	513,225	391,418	593,422	784,164	793,297	1,028,649	891,430	925,370	938,519	831,024	456,728	860,733	1,056.979	777.042	867.097	[illegible]
Summit	185,500	253,148	145,134	82,225	95,815	112,024	84,438	189,362	143,549	110,299	97,040	27,322	49,260	53,666	83,238	65.375	[illegible]
Trumbull	500,612	257,683	264,517	188,531	167,989	157,826	106,480	105,333	64,173	55,775	23,152	33,137	29,809	7,172	10,588	7.471	[illegible]
Tuscarawas	394,066	317,141	285,545	267,666	506,466	546,117	643,866	565,105	733,374	887,106	794,681	651,903	753,286	613,563	730,473	950,913	[illegible]
Vinton	47,800	69,740	77,127	60,013	89,727	108,695	98,749	86,611	104,366	88,305	76,144	62,496	61,068	46,503	75,445	85.144	[illegible]
Washington	......	5,600	5,000	5,500	1,880	2,432	2,770	3,835	3,796	3,480	1,936	2,000	4,533	3,646	2,974	3,634	[illegible]
Wayne	162,847	120,571	81,507	109,057	105,150	91,157	86,549	71,431	91,553	80,188	64,934	32,142	119,015	69,058	84,052	41.798	[illegible]
Morgan	......	7,636	5,536	4,370	4,100	......	......	......	......	19,000	14,500	13,599	17,930	19,080	22,165	26.340	[illegible]
Scioto	......	3,650	2,440	......	......	......	......	1,090	......	1,180	769	1,391	3,875	1,785	17,119	12.140	[illegible]
Monroe	......	......	......	......	......	......	......	......	......	......	4,868	2,411	5,483	2,835	2,807	4.451	[illegible]
Total	8,902,729	7,650,062	7,816,179	8,435,215	10,301,700	10,910,946	10,907,385	11,788,859	13,050,187	14,599,908	14,828,097	11,910,219	13,683,879	12.912,608	12,448,822	14,058,135	[illegible]
Total tons produced, year 1828 to 1912, inclusive	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......
Total production to 1912	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......

…UCTION OF COAL IN OHIO BY COUNTIES YEARS 1883-1912.

[illegible]	1895	1896	1897	1898	1899	1900	1901	1902	1903	1904	1905	1906	1907	1908	1909	1910	1911	1912	Totals
[illegible]	1,435,744	1,383,709	1,299,454	1,533,188	1,761,775	2,594,859	3,066,533	3,666,993	3,905,904	3,854,078	3,848,440	4,370,912	4,753,044	4,170,995	4,354,074	5,943,638	4,532,595	4,586,476	[illegible]
[illegible]	961,367	1,082,964	905,378	1,168,567	1,259,520	1,595,369	1,544,832	2,058,066	2,612,025	3,283,089	3,871,846	4,467,295	6,355,582	5,591,719	5,993,418	8,336,428	8,040,333	[illegible]	[illegible]
[illegible]	326,670	278,296	162,537	261,535	212,051	205,641	254,510	251,652	326,095	354,594	235,826	209,360	371,542	439,080	398,085	309,328	269,687	310,018	[illegible]
[illegible]	644,823	516,005	735,041	886,053	799,474	718,108	792,533	868,426	874,602	721,144	705,824	554,047	686,585	516,780	714,325	740,345	668,039	[illegible]	[illegible]
[illegible]	161,723	342,625	326,981	342,904	364,702	366,145	360,635	410,309	422,221	326,467	388,932	358,128	397,229	366,805	390,302	435,903	438,369	356,299	[illegible]
[illegible]	10,341	6,671	15,704	17,391	14,470	16,138	15,740	26,450	23,889	18,979	18,551	43,895	36,635	13,692	9,920	13,923	17,114	27,723	[illegible]
[illegible]	972,505	1,068,453	861,776	1,176,524	1,313,774	1,904,381	2,094,887	2,968,108	2,715,946	3,084,220	2,896,526	3,348,934	4,009,141	2,926,448	3,108,686	4,473,022	3,901,529	4,333,963	[illegible]
[illegible]	[illegible]	28,391	28,159	38,144	29,852	36,087	111,847	293,841	249,106	307,206	402,679	335,928	489,118	447,805	576,162	599,741	476,914	[illegible]	[illegible]
[illegible]	1,432,741	1,351,511	1,381,414	1,254,740	1,929,753	2,311,679	2,348,869	2,118,805	1,967,636	1,894,869	1,695,763	1,553,507	91,32,616	1,282,647	1,036,743	1,451,147	1,547,839	2,046,175	[illegible]
[illegible]	12,665	10,164	19,313	15,601	12,321	12,966	16,548	17,187	32,099	30,850	24,820	43,080	14,447	18,768	15,844	13,203	11,242	[illegible]	[illegible]
[illegible]	2,072,939	1,651,199	1,649,493	1,804,792	2,179,757	2,319,321	2,141,466	2,316,123	2,412,116	1,958,538	1,887,904	1,452,176	1,303,529	836,997	823,034	933,238	673,663	[illegible]	[illegible]
[illegible]	861,185	670,867	744,790	829,526	935,975	971,209	1,303,308	1,789,452	2,320,419	2,495,375	3,337,799	2,998,476	4,648,263	3,565,008	4,056,148	5,111,563	4,321,829	[illegible]	[illegible]
[illegible]	125,280	81,746	124,448	68,835	135,064	112,873	143,678	186,635	249,139	194,192	212,949	257,049	246,562	180,265	214,685	190,465	84,567	[illegible]	[illegible]
[illegible]	101,866	52,277	92,283	75,149	74,309	109,348	52,765	94,773	89,218	86,495	117,074	121,412	95,280	86,326	63,974	66,312	64,276	[illegible]	[illegible]
[illegible]	265,411	195,669	159,987	147,714	158,216	152,767	183,391	139,933	136,803	103,910	91,205	104,729	47,181	18,103	12,465	27,604	16,942	10,395	[illegible]
[illegible]	216,897	259,296	203,861	193,335	225,149	249,060	255,892	340,700	388,568	212,395	370,587	530,476	375,033	482,630	543,595	648,149	532,840	635,940	[illegible]
[illegible]	255,230	264,105	339,660	250,718	220,854	311,547	226,375	286,532	305,933	300,310	242,011	368,320	442,278	436,947	416,217	270,416	410,777	522,198	[illegible]
[illegible]	19,376	42,507	63,967	62,912	66,714	89,046	82,844	34,992	52,247	154,970	171,509	409,114	309,349	208,192	379,055	441,823	480,524	641,677	[illegible]
[illegible]	[illegible]	1,703,816	1,449,178	1,789,890	1,748,522	2,517,258	2,563,051	2,830,962	2,731,595	2,491,682	2,390,570	2,609,701	2,921,754	2,108,050	2,076,407	2,394,961	2,021,594	2,164,130	[illegible]
[illegible]	[illegible]	48,060	79,245	75,851	114,778	103,241	86,781	97,928	101,889	97,692	83,603	109,227	96,463	88,543	102,624	105,155	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	1,056,979	777,042	867,097	1,073,750	1,150,232	1,049,093	1,184,749	926,180	761,173	774,832	772,583	737,017	524,052	458,392	547,635	442,860	[illegible]	[illegible]
[illegible]	49,260	53,666	83,238	65,378	86,100	122,988	123,541	93,586	44,329	84,208	115,529	96,997	99,971	103,299	78,268	94,346	85,711	[illegible]	[illegible]
[illegible]	29,869	7,172	10,838	7,471	11,059	19,181	12,148	8,143	8,476	6,635	3,591	1,956	1,895	7,534	5,405	4,716	3,496	[illegible]	[illegible]
[illegible]	753,286	613,563	730,473	950,913	1,053,938	1,267,185	1,324,570	1,577,654	1,328,951	1,296,876	1,361,394	1,429,565	1,776,566	1,331,248	1,513,900	811,782	670,251	1,311,301	[illegible]
[illegible]	61,068	46,503	75,445	85,144	71,072	77,231	88,024	110,423	154,934	240,524	224,275	220,904	249,475	183,542	128,728	159,006	129,986	[illegible]	[illegible]
[illegible]	4,533	3,646	2,974	3,634	2,090	2,679	1,738	3,930	4,000	3,800	3,600	1,920	691	1,304	1,232	....	355	[illegible]	[illegible]
[illegible]	119,015	69,058	84,052	41,598	18,557	45,566	31,530	94,015	97,952	123,520	165,224	204,573	204,773	125,525	86,987	164,724	202,329	[illegible]	[illegible]
[illegible]	17,930	19,080	22,165	26,940	24,881	29,954	33,504	50,437	82,315	83,700	173,551	222,891	290,422	217,036	187,241	126,544	175,699	[illegible]	[illegible]
[illegible]	3,875	1,785	17,119	12,140	8,424	11,657	10,349	8,351	8,515	12,224	9,013	10,331	13,508	8,460	8,916	9,834	5,599	7,794	[illegible]
[illegible]	5,483	2,835	2,807	4,451	2,720	2,933	308	132	164	....	....	....	....	....	....	....	....	180	[illegible]
[illegible]	13,683,879	12,912,608	12,448,822	14,058,135	15,908,934	19,426,649	20,321,290	23,929,267	24,573,266	24,583,815	25,834,657	27,213,495	32,365,949	26,287,800	27,755,032	34,424,951	30,342,029	34,444,291	[illegible]
....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	[illegible]
....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	[illegible]



TRUMBULL
PORTAGE
MAHONING
PALMYRA FIELD
No 1 COAL
PALESTINE & LISBON FIELD. Nº 3, 6 & 7 COAL
COLUMBIANA
MEASURES
MASSILLON FIELD
Nº 1 COAL
STARK
COAL
WESTERN BOUNDARY OF OHIO
HOLMES
CARROLL
SALINEVILLE FIELD Nº 3 COAL
SHERRODSVILLE FIELD Nº 5, 6 & 7 COAL
BERGHOLZ FIELD Nº 6 COAL
HARRISON
COSHOCTON Nº 5, 6 & 7 COAL FIELD.
EASTERN OHIO OR Nº 8 COAL FIELD.
GUERNSEY
MUSKINGUN
CAMBRIDGE Nº 7 & 8A COAL FIELD
APPROXIMATE
O H I O
THIN VEIN Nº 6 HOCKING COAL FIELD
MONROE
THICK VEIN Nº 6 HOCKING COAL FIELD.
Nº 8 COAL FIELD
ATHENS
WELLSTON FIELD
Nº 1, 2, 3, & 4 COAL
JACKSON
POMEROY Nº 8 COAL FIELD.
PLEASANTS
RITCHIE
WIRT
MASON
ROANE
BRAXTON
KANAWHA
WAYNE
NICHOLAS
WEST VIRGINIA
PENNSYLVANIA
COMERCIAL COAL FIELDS
RECOGNIZED BY THE COAL TRADE
F. A. RAY COLUMBUS O.
-1913.-
THE OHIO COAL FIELD

OHIO COAL DISTRICTS.

The development of the present commercial Ohio coal fields began in most cases with the building of the railroads into them. Some coal was shipped by canal in the early days, but the amount was small in comparison to that produced from the rail coal fields developed later.

There are fifteen districts in the State in which coal is mined from one or more of the nine different seams.

The production of coal from the **Wellston** and **Ironton Fields** began with the completion of the C., H. & D. and the D., T. & I. Railroads about 1880. The Wellston and Jackson fields have been actively producting coal from Nos. 1, 2, 3, and 4 coal seams for about thirty-four years.

The development of the **Hocking Thick and Thin Vein No. 6 Field** began in a small way with the construction of the Hocking Valley branch of the Ohio canal. The first mines were located at Chauncey and Nelsonville. The best market at that time was the old Neil House at Columbus. The production of coal from this field did not reach any degree of importance until the building of the Hocking Valley Railroad to Nelsonville in 1869, which was followed by the construction of the Straitsville branch a year later. The Shawnee branch of the B. & O. Railroad was completed to Shawnee in 1872. The Toledo & Ohio Central Railroad was completed to Corning about 1879. The Columbus, Shawnee, and Hocking Railroad was completed to Redfield and Canalville in 1883. The Kanawha and Michigan Railroad was built in 1882. The building of these railroads fixes the time that this field has been active at about 34 years. The most of the production has been from the thick vein No. 6 coal, although some of it has come from the No. 7 seam. The production of the thin vein began about 12 years ago.

Coal began to be shipped from the **Pomeroy Field** by river about 1833. Three years later the first tow boat was built, and the towing of coal in barges began on the Ohio River at Pomeroy. The shipping of all rail coal began in this field at the completion of the Hocking Valley and K. & M. railroad connection to Pomeroy in 1892. The production has all come from the No. 8 seam.

The development of the **Cambridge Field** began in the No. 7 seam with the completion of the Cleveland and Marietta Railroad from Marietta to Canal Dover in 1874. The period of activity in this

field, therefore, has been 40 years, and the production has been largely from the No. 7 seam.

The Eastern Ohio No. 8 Coal Field development was begun by Jacob Heatherington and his mule, "Jack," on a three-acre lease near Bellaire in about 1830. The coal was flat-boated to points along the Mississippi River for the use of sugar refineries.

The all-rail coal development in this field has all been made since the completion of the direct railroad outlets to the lakes, and the extension of the Pennsylvania lines into this coal field. The largest development has been within the last twelve years, which has been mainly from the No. 8 seam.

The Coshocton and the Sherrodsville Fields are both located on the main line of the Pennsylvania Railroad, and each is provided with an outlet north to the lakes by the Wheeling and Lake Erie Railroad. The development of these fields dates to the completion of these railroads, which was about 1880. The coal seams worked are No. 5, 6, and 7.

The Bergholz Field began to develop on the completion of the L. E. & W. Railroad about 1884, in the No. 6 coal.

The Salineville Field began with the building of the C. & P. Railroad, and its connection north to the lakes in the No. 3 and No. 6 coal seams.

The Palestine and Lisbon Coal Fields were developed by the building of the P., F. W. & C. Railroad. This field is producing coal from the No. 3, 6, and 7 seams.

The Palmira Field was brought into operation by the P. L. E. & W. Railroad. Probably the first coal systematically mined in Ohio was mined at Tallmadge, Ohio, and was shipped to Cleveland by Henry Newberry in 1828. It was offered to steamboats as a substitute for wood. The value of Summit County coal was not fully recognized until twenty years later. About this time Governor Todd began mining at Youngstown, and shipments were made by canal. It is claimed that coal was first discovered at Tallmadge, Ohio, in 1825 by F. H. Wright while digging a ground hog out from under a stump. There is some doubt as to where and by whom the discovery of Ohio coal can be credited, since there are varying references made on some of the public records and maps bearing dates of about this time.

The Massillon Field was developed by the Cleveland and Mahoning Railroad, which was completed in 1864. Both the Palmira and Massillon fields are producing coal from the No. 1 seam.

The most important of the fifteen coal districts are the Eastern Ohio No. 8 Coal Field, the Thick and Thin Hocking No. 6 coal, and the Cambridge No. 7 Coal District. These three districts alone originally contained two-thirds of the proven Ohio coal reserve.

The annual production of coal from these three districts amounts to over eighty per cent. of the total annual coal production for Ohio.

THEORY OF COAL FORMATION.

Dr. Edward Orton has said, "Every coal seam was formed at the ocean level; to the generation of a coal field three conditions are indispensable: (1) An abundant growth of vegetation. (2) This growth located at the level of the sea. (3) Oscillations of the earth's crust. All are present in the carboniferous age, not only for this continent, but in Europe and Australia as well. In other portions of the world, and even in our own country, in the Rocky Mountain region, coal fields have been developed at other points in the geological scale, but the same conditions can be traced in all to the very existence of the seam."

It is now believed that the coal regions were at one time a part of the sea and that vast growths of vegetable matter accumulated along the shores, during long periods when the earth's crust was at rest. Following this came a period when the earth subsided when the vegetable growth was covered by the sea and upon which were deposited silt and sand, and at times a growth of limestone.

The action during long intervals of time furnished the shales, the sandstones, and the limestones which "covered the vegetable accumulation with appropriate deposits, to compress them so as to work the strange transformation of vegetable tissue into coal."

The geological column of a coal field shows many coal seams one above another: "Each one standing as it does for a long period of growth, is covered through a movement of subsidence which lets in the sea with its burden of silt and sand."

"We have several examples in our Ohio scale where the sea has held quiet possession long enough to roof over the buried coal swamp with a layer of limestone that requires for its growth a period comparable with that required for the growth of the coal seam itself." If we grant that this theory correctly accounts for the formation of coal seams, then it will require but little imagination for us to see that favorable conditions for the growth of a coal seam would not

likely be equally good in all parts of a region. The subsidence may have been more in one place than in another. The conditions for the growth of vegetation may have more favorable in some places than at others. The periods of rest may have been of shorter duration in the formation of one seam than in another, all of which would explain the irregularities found in coal seams. The large areas of barren territory, the many slate partings, and the inferior quality of some coals, result in the uncertainty of a coal seam carrying true for any considerable distance.

From this theory of coal formation it naturally follows that each of the coal seams forms comparatively narrow strips of coal bordering the sea where it grew. There has been much speculation as to how far back from the outcrop the various coals extend in minable thickness under cover. Some of our greatest geologists place this distance for Ohio coal fields at about 25 miles. None of the coal seams are supposed to cover the entire basin or region. Recent drillings have proven that several of the coal seams may carry true more than a hundred miles from the line of its outcrop.

All of the Ohio coal formations have a general dip of about 30 feet to the mile towards the Ohio River. Haselton's World's Fair charts showed the various Ohio coal seams to cover the entire erea occupied by the coal measures in an unbroken blanket. This made an impressive exposition of Ohio Coal Reserve, but it was far from the truth.

CLASSIFICATIONS OF OHIO COAL SEAMS.

Some years ago the late R. M. Haselton published a stratigraphical chart, which faithfully shows the order and the generally accepted classification and names of all of the coal seams found in the Ohio scale.

The classification of the coal seams in the Appalachian Region was first made by Professor Lesley for Pennsylvania. He attempted to name the coal seams alphabetically in the order of their occurrence, beginning with the lowest coal in the scale.

Professor Newberry afterwards adopted Lesley's order for the Ohio coals but named them numerically in their order from the bottom upwards. Later Dr. Orton found that Newberry's classification was incomplete and that there were several coal seams that had been left without place or name in the Ohio scale. This made it necessary for him to revise the classification into its present accepted form.

OHIO

CARBONIFEROUS SYSTEM

J. C. M. Haseltine, Columbus O. Consulting Mining Engineer, Ex Chief Inspector of Mines, Special Coal Expert U. S. Geological Survey			Classification of Measures	Groups	No.	Coal (Local Name) and Intervening Strata	Thickness of Vein	Thickness of Strata	Distance between Horizons	Where Mined
Upper — Fresh water deposits	Permo-Carboniferous or (Dunkard Creek Series)				Section taken from Monroe and Washington Cos.	Coal Blossom Shales Limestone Shales Sandstone			Additional Notes on Ohio: Coal 7b. Patriot of Gallia Co " 7a: Bonnaville Strip " 7 = Norris Coal " 6c. Steubenville Shaft " 6 = Hammondsville Strip " 5 Sneerleys potters clay at Smith's Ferry Upper Clarion Coal = Limestone Coal of Vinton Co. Coal 3b. Strawbridge cannel of Holmes Co " 3a. Hunnewell cannel & Bedford Cannel of Coshocton Co L. Mercer, Ferriferous & U. Freeport Limestones are important horizons	
						Jollytown Coal Shale Limestone Sandstone Shales	0-1½	50-200		
						Washington Coal (Split) Limestone Sandstone Shale & Coal (Waynesburg) Shale	1-3	100-200		
	Upper Coal Measures		Upper Coal Measures (Stevenson)	Monongahela Series	No. 8b	Macksburg (Waynesburg) Shales Limestone	0-4			Noble Co.
					8a	Meigs Creek (Cumberland) Shale Limestone	4			Barnesville, Cumberland
					8	Pittsburgh	6			Bellaire, Dillonvale, Pomeroy
	Barren Measures		Lower Barren Measures (Stevenson)			Shales Limestone Shales		150-200		Maynard
					7b	Norwich, Muskingum Co. Shales Limestone (Crinoidal; Ames) Shales Sandstone Shales	2	90		Vinton Co., Gallia Co Muskingum Co
					7a	Groff Vein, Strip Vein (U. Cambridge) Limestone Mahoning coal Sandstone (Upper Mahoning) Mahoning Coal Sandstone (Lower Mahoning) Shales	3½-5½ 1½ 1½	30-70		Yellow Creek, Salineville
Middle — Shore Deposits with incursions of the sea	Lower Coal Measures No. XIII Allegheny River Series		Lower Coal Measures (Stevenson 1900)	Freeport Group	7	Cambridge, Big Vein Denver Clay Limestone Limestone (Upper Freeport) Iron Ore	5-7	25 3		Sherrodsville, Salineville, Bell Roy, Cambridge, Happy Hollow, Waterloo
					6b	Hatcher, Whan, Roger Vein Cement Rock (Lisbon O) Sandstone (Lower Freeport)	3-5			Hatcher, Hampden Furnace, Roger, Steubenville, Lisbon
					6a	Upper Kittaning Fire Clay Sandstone Limestone & Buhrstone Shales	1½	1½ 15½ 3½		(Not mined in Ohio)
					6	Middle Kittaning (Sheridan) Fire Clay Shales Iron Ore (Baird) Sandstone	2½-13	3 5 ¾ 27		Osnaburg, Goshen, Pike Run, Conesville, H. Valley, Dennison, U. Zanesville, New Lexington
				Ferriferous Limestone Group	5	Lower Kittaning Vanport Vein, Shire-paddle clay Buhr Stone Ore Ferriferous Limestone Block Ore Putnam Hill Grey Hanging Rock L.	2½	7½-22 7½		New Castle, Leetonia O, Ironton, Redfield, Mineral Point, Hammondsville
						Upper Clarion Fire Clay Sandstone (white)	1-6	6		Canfield (as Cannel Coal), Colemans, Columbiana Co
						(Not present in Ohio) Shales				
					4	Brookville Coal	2			Jackson Co. Vinton Co.
	Conglomerate Measures "Great Seral" No. XII		Serial Conglomerate (1900)			Sandstone (Homewood or Piedmont) Shales		30		
					3b	Tionesta Coal Upper Blue Limestone (U. Mercer) Fire Clay Shales Flint Limestone (Gore)		2½		Greentown, N. Industry, Bolivar, McArthur, Vinton Furnace
					3a	Bruce Coal (Bryce) Fire Clay Shales and Sandstone Iron Ore Limestone (L. Blue (L. Mercer) Boar) Shales	1-7	1-2 20-70 2-6		Canfield Tp. Lawrence Co. The Boar Limestone is one of the best marked geological horizons in L.C.M.
					3	Wilbur Coal (Flint Ridge) Fire Clay Shales Sandstone (Massilon) upper	3	3-15 7 30-50		Millersburg, Wick. McDowell, Austintown, Flint Ridge, Licking Co.
					2	Wellston Coal Clay Shales Sandstone (L. Massilon) Gray Slate	1½-4½	1-3 20-30 20-80 25-40		Wellston, Vinton
					1	Brier Hill, Block Fire Clay Sandstone and Shales Conglomerate Sandstone	3-5	3-5 10-50		Youngstown, Massilon, Mineral Ridge, Jackson
Lower — Marine Deposits	Mauch Chunk, Red Shale, Umbral Limestone, Greenbrier, etc. No. XI Pocono Sandstone, Vespertine No. X, Big Injun Oil Sand					O H I O				
			Classification of Measures	Groups	No.	Coal (Local Name) and Intervening Strata	Thickness of Vein	Thickness of Strata	Distance between Horizons	Where Mined

COAL SEAMS MINED IN OHIO.

There are 19 seams of coal in Ohio, of which 16 are mined more or less at one or more places within the State. At present only nine of these seams are being mined in Ohio to any great extent, and of these, five are producing more than three-fourths of the State's present total annual production.

The No. 1 Coal Seam is the lowest of the minable seams in Ohio. It is an open burning coal and is usually of very high quality, although there are many graduations of quality. This coal is mined in the northern part of the State in Portage, Summit, Stark, and Wayne Counties, and in the southern portion of the State in Jackson and Vinton Counties. This product is very uncertain and lies in small detached bodies rarely exceeding 200 acres in area. This seam has a very uneven floor and does not exceed six feet in thickness, with an average thickness of three feet. The minable area of this coal is small and a considerable part of it is now exhausted.

The No. 2 Coal Seam is found in minable thickness in Jackson, Vinton, and Hocking Counties. The coal is of excellent quality. It is high in moisture, but contains less ash than any other Ohio coal. The largest minable area is found in the center of Jackson County. This area is now nearly exhausted. There is an area of undeveloped No. 2 coal along the line between Vinton and Hocking Counties.

The No. 3 Coal Seam is mined in Mahoning, Columbiana, and Vinton Counties. Though occurring in 13 counties in Ohio it is not an important coal seam. The coal is liable to be found too impure for market purposes. The thickness varies in different localities, but will average about 3.5 feet in the counties that we have credited with minable areas of this coal.

The No. 4 Coal Seam is widely distributed and is on the whole a more valuable seam than the No. 3 coal. There are shipping mines in this coal in Carroll, Gallia, Vinton, Jackson, and Scioto Counties. It is mined in a small way in several other counties in the State.

The Ohio State Geological Survey states that the No. 4 coal seam acquires its largest volume, and perhaps its greatest value, in Coshocton County. There are no mines credited to Coshocton in this coal seam. The coal will average 4 feet in thickness for areas that we have taken into account. This coal is high in ash and sulphur, but is a desirable domestic and steam coal, which will become more important as the more desirable coals become exhausted.

The No. 5 or Lower Kittanning Coal Seam is one of the most important seams of the State. It is mined in Carroll, Gallia, Jackson, Lawrence, Mahoning, Tuscarawas, and Vinton Counties. This seam has great steadiness. It is found from two to five feet in thickness and will average 3.25 feet of clean coal on the areas I have considered in making my estimates of proven coal reserves. This coal is so closely connected with its companion, the No. 6 or Middle Kittanning Coal, that a discussion of the stratigraphical relations of the one fits the other.

The Kittanning coal seams have been traced around the whole northern margin of the Appalachian field from Maryland on the east to the central part of Kentucky on the south.

The No. 6 or Middle Kittanning Coal Seam is one of the three most important coal seams of the State. It is found from 20 to 50 feet above the No. 5 coal. In Western Pennsylvania it is generally found thin. On the State line there is a small area where it becomes cannel coal, but after crossing the Ohio line it resumes its normal character. In the Yellow Creek Valley in Jefferson County the No. 6 coal becomes an excellent coking coal but rather high in ash. In Columbiana County the seam is thin but generally present. It is minable in Stark County and is thicker in Tuscarawas County where it is generally mined. It carries generally true to McCuneville, Perry County. Throughout this territory the seam is very persistent and regular in every way. Its maximum thickness is from 4 to 5 feet, and its average thickness is 3.5 feet of clean coal. From McCuneville south and westward the seam thickens. There is a large area amounting to about 224 square miles in Athens, Hocking, and Perry Counties, where this coal is from 5 to 13 feet thick, and is locally known as Thick Vein Hocking. This area of thick coal is roughly bounded by the outcrop, on the west; the B. & O. Railway, on the south; the T. & O. C. Railway, on the east, and the Shawnee branch of the B. & O. and the old C., S. & H. Ry. to Corning, on the north. The coal within this boundary averages 7 feet thick. The thin vein No. 6 coal comes in east of Corning and is found of minable thickness east and north everywhere that explorations have been made. It is either thin or cut out entirely for a large area around Amesville, Athens County. The average thickness of the thin No. 6 coal is 3.5 feet of clean coal.

Much of the thick vein No. 6 seam is cut out by the Jumbo Fault, amounting to at least 37 square miles from the center of the thick vein field. This seam is thin in Jackson County, but is somewhat thicker in Gallia and Lawrence Counties. The No. 6 seam is an excellent

domestic coal. It is hard and stands rehandling. It is very desirable for lake shipment.

The No. 7 or Upper Freeport Seam ranks third in importance of the Ohio coals. It is mined in Athens, Carroll, Columbiana, Guernsey, Muskingum, Noble, and Tuscarawas Counties. The most important production is from Guernsey County. Generally the coal is moderately cementing, has well-defined cleavage planes, is somewhat soft with medium amount of ash and is liable to be high in sulphur. It is a good steam coal, but does not stand rehandling. Its floor is generally regular. The roof is either a few feet of shale or the Mahoning sandstone. In places this sandstone forms the roof, and has cut out a part or all of the coal. Dr. Orton stated that the strong currents that brought in the sandstone have carried away the shale, and have cut channels of varying widths throughout the body of coal in all fields of No. 7 coal thus far explored, creating "wants," or "horsebacks". These troubles are serious drawbacks to the mining of this coal and render untested areas very uncertain.

The No. 8 or Pittsburg Coal is known to be the most valuable coal seam in North America. In all of the states where it occurs it is important. It is found in Pennsylvania, West Virginia, Maryland, and Ohio. The total area in these states is estimated to be from 6,000 to 7,000 square miles. Dr. Orton estimated the area for Ohio alone at 1,250 square miles. There are two distinct fields in Ohio. The Eastern, which is the most important, underlies the whole of Belmont County, the southern half of Jefferson, the eastern portion of Guernsey, probably the northern portion of Monroe, and the northeastern portion of Noble County. The Southern field occupies portions of Morgan, Athens, Meigs, and Gallia Counties.

This coal seam is usually persistent and of characteristic structure. It is at its best along the river in Jefferson and Belmont Counties. Farther west in this field the structure is less constant. In Athens County the structure is decidedly changed. Instead of the usual three benches with the attending slate partings, we have two benches separated by a heavy clay parting. The coal here is not persistent, and is often found with either the top or both benches missing. Dr. Bownocker states, that the Meigs County coal that Dr. Orton named the No. 8 is in reality the Redstone seam that comes about 20 feet above the No. 8 coal.

For the purpose of this publication it has been considered as No. 8. The Pomeroy coal is a very valuable coal for domestic and steam

purposes. The whole of the county has been explored and the limits of minable coal are definitely defined. The clean No. 8 coal will average a little more than 4 feet thick.

The No. 8 coal will coke, but in Ohio its sulphur content is too high to make a coke suited for metallurgical purposes. The Black Diamond Company are making a satisfactory domestic coke at their mines at Lathrop, Ohio. The No. 8 seam promises to live the longest of any of our Ohio coals.

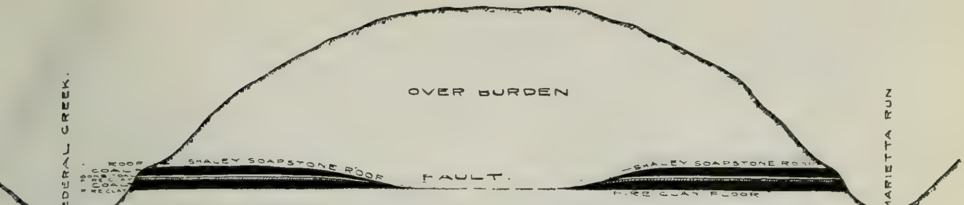
The No. 8-A or Meigs Creek Seam has an irregular floor and roof, especially the latter, which would indicate that the conditions under which it was formed were not uniform. This coal lacks persistence. It is a dirty coal, high in ash and sulphur. There is one small operation mining in this seam at Hiramsville, Noble County. I have included this coal seam in my estimate of coal reserve wherever the Ohio Geological Survey has shown a considerable area 3.5 feet or more in thickness. Minable areas are present in Belmont, Harrison, and Noble Counties. While there is at present no demand for this coal there will come a time in the future when it will be of great value.

There are many thin seams of coal that we have not taken into consideration. They are in the most part too thin or too inferior to be minable at present. Most of these thin seams will undoubtedly have value some time in the future.

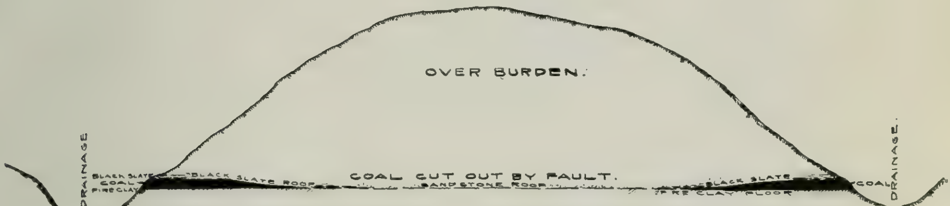
THE UNCERTAINTY OF THE COAL SEAM AND THE DIFFICULTY OF ESTIMATING THE COAL RESERVE WITHOUT FULL KNOWLEDGE.

From what has already been said it will be seen that the coal seams have distinctive characteristics in different parts of the State. The same seam is found in minable condition in one locality, and is either absent or worthless at another. Not one of the seams continues unbroken, of uniform thickness or quality over the coal bearing area. The theory of coal formations suggests that each coal seam must constitute a relatively narrow strip of coal of indefinite width bordering the arm of the sea around which it grew. The mining of the various coal seams has exposed many kinds of faults, replacements, or cutouts, which have rendered a portion of the area unminable or worthless. Some of the coal seams have been found more dependable than others, yet experience has taught us that it is very unsafe to take for granted that any of them will hold true in character and quality through any considerable area.

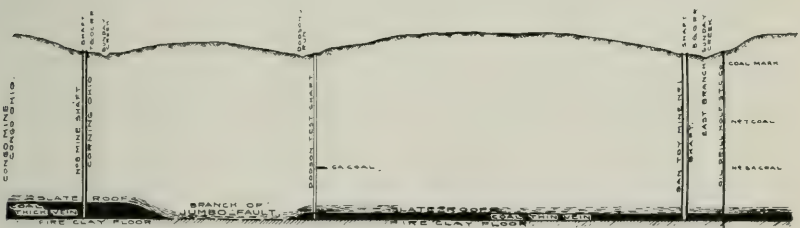
Specific Examples Showing Irregularities in Coal Seams.

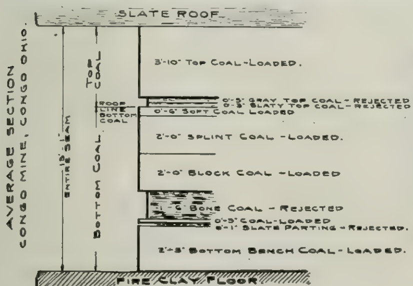


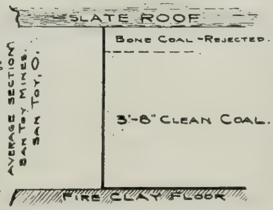
TYPICAL SECTION No 8 COAL SEAM – JENNINGS MINE UTLEY OHIO.

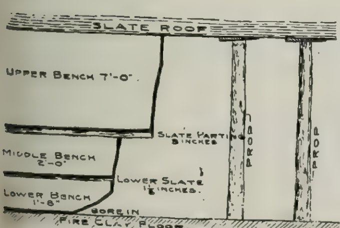


TYPICAL SECTION No 2 COAL SEAM – NORTH OF ALLENSVILLE VINTON CO. OHIO.

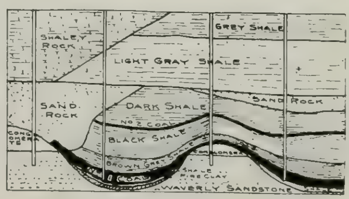




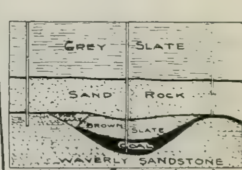




Section of Straitsville Coal.

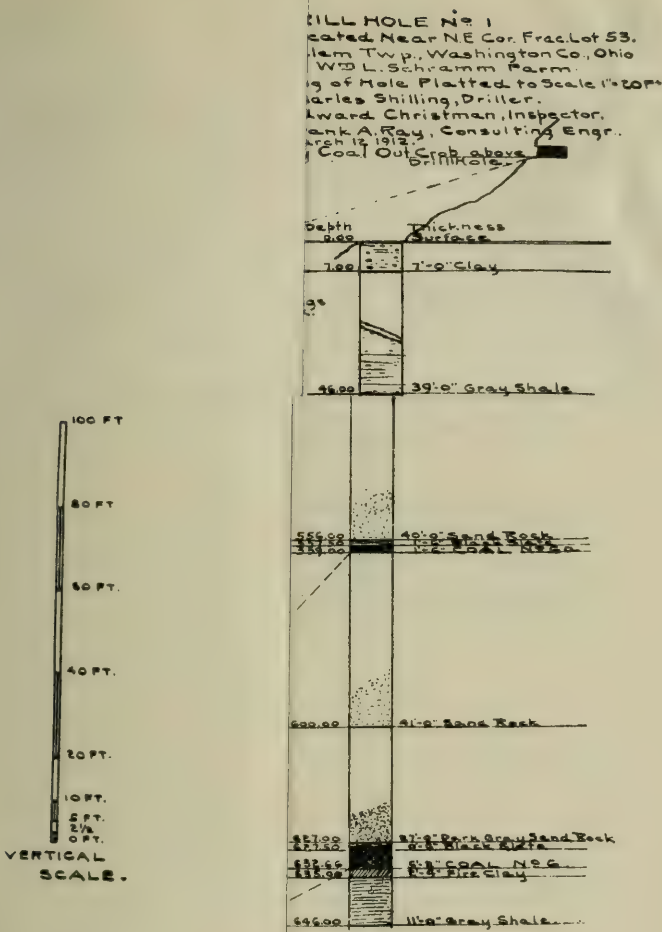


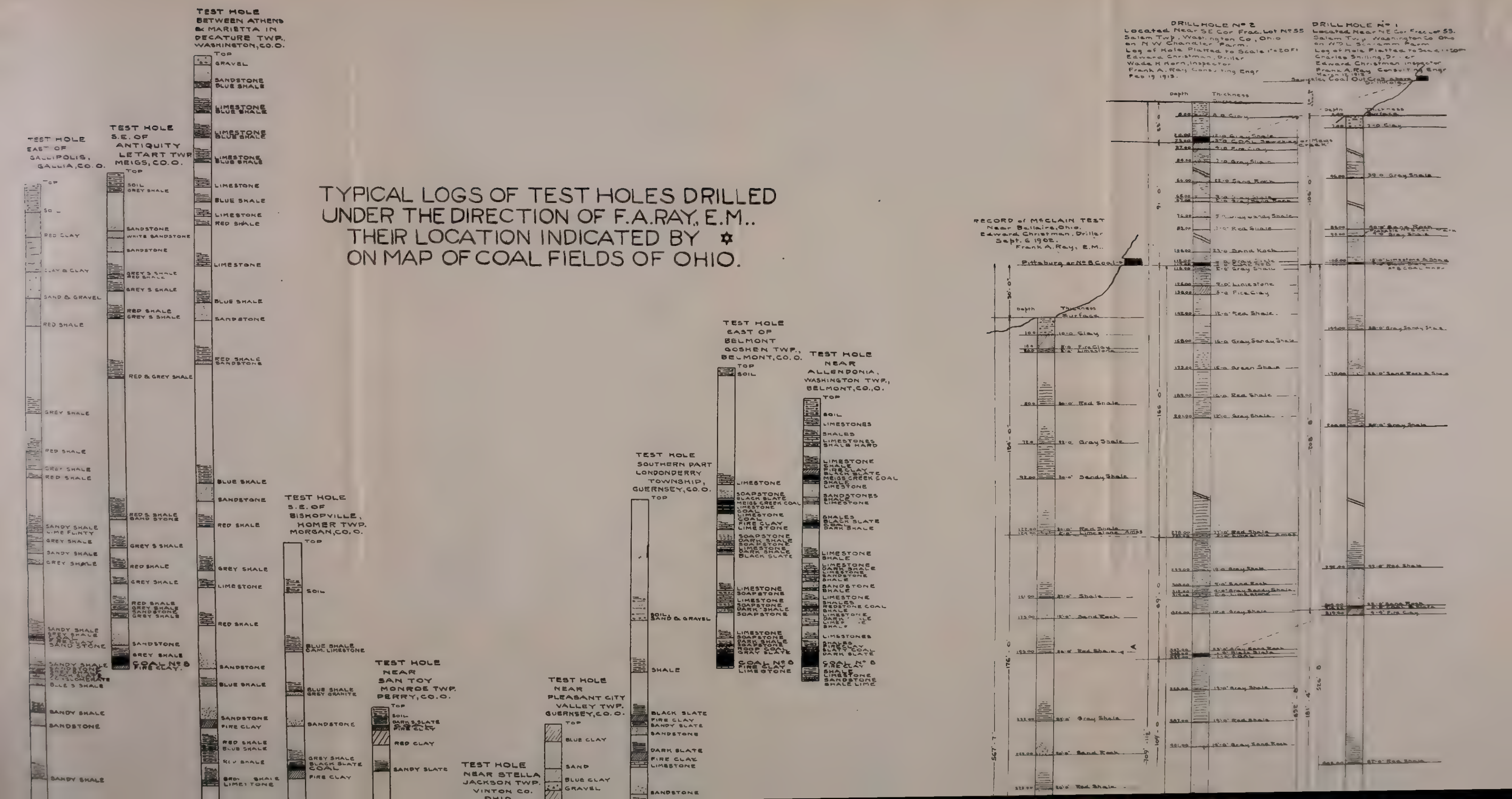
Section of Strata in Mahoning Valley.

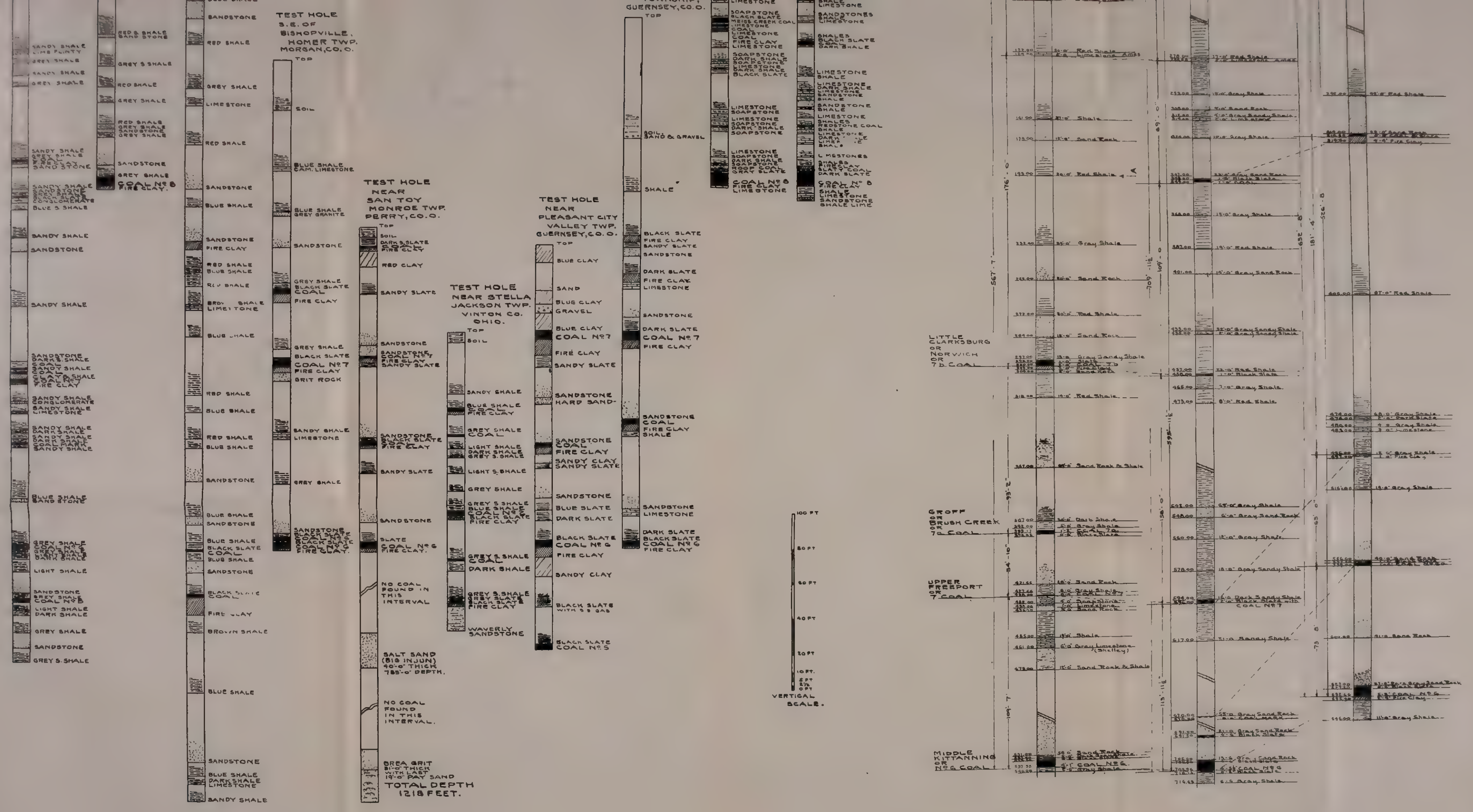


Section of Strata in Mahoning Valley.

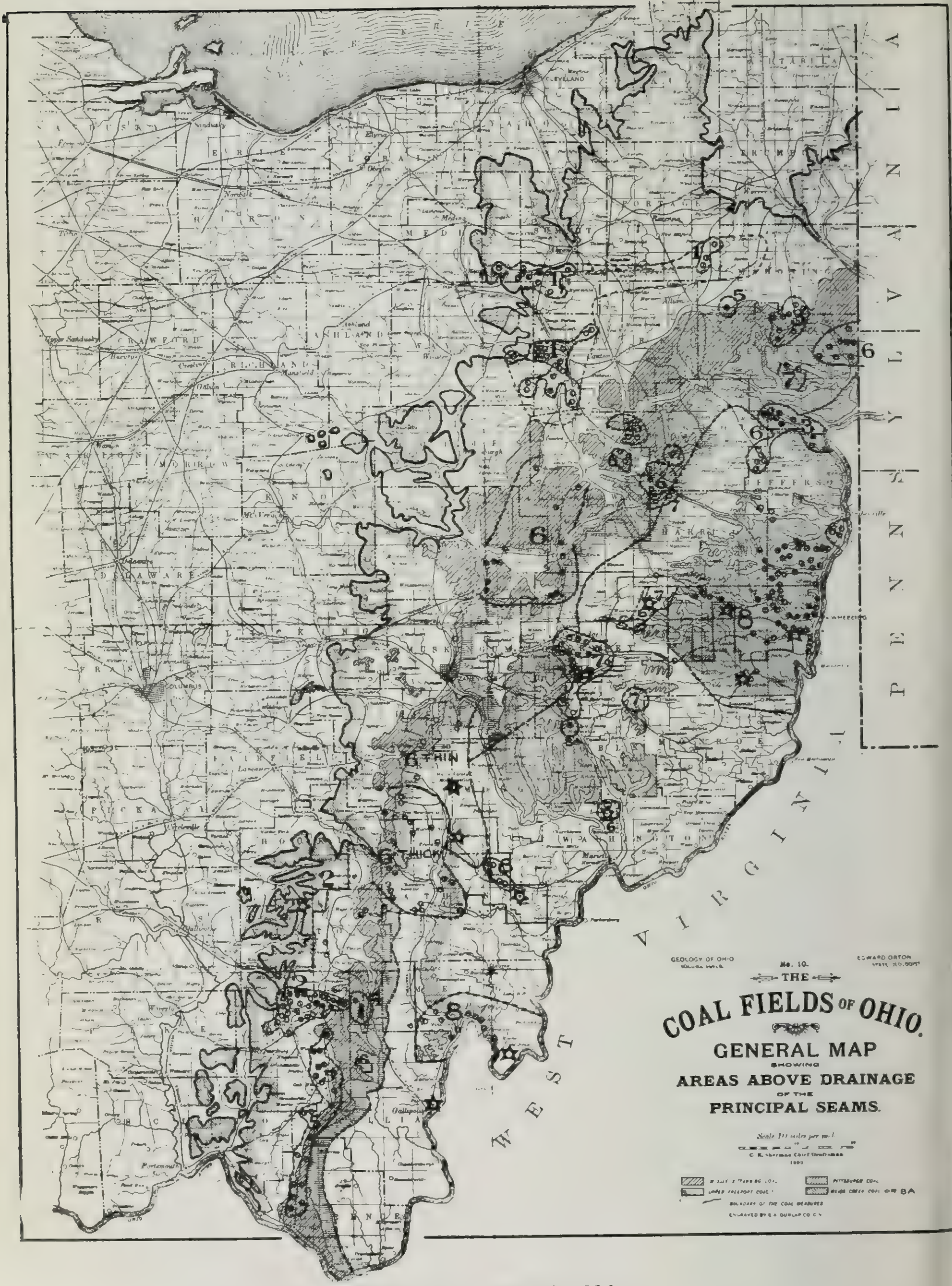
The Jumbo Fault.


ILL HOLE No 1
cated Near N.E Cor. Frac.Lot 53.
lem Twp., Washington Co., Ohio
WM L. Schramm Farm.
g of Hole Platted to Scale 1"=20Ft
arles Shilling, Driller.
lward Christman, Inspector.
ank A. Ray, Consulting Engr.
rch 12 1912.
Coal Out Crop above
Drill Hole
Depth
Thickness
0.00
Surface
7.00
7'-0" Clay
46.00
39'-0" Gray Shale
556.00
40'-0" Sand Rock
600.00
41'-0" Sand Rock
627.00
627.50
0-6" Black Slate
632.66
5'-2" COAL No 6.
Fire Clay
646.00
11'-0" Gray Shale
100 FT
80 FT
60 FT.
40 FT.
20 FT.
10 FT.
5 FT.
2½
0 FT.
VERTICAL
SCALE.


TYPICAL LOGS OF TEST HOLES DRILLED UNDER THE DIRECTION OF F.A.RAY, E.M.. THEIR LOCATION INDICATED BY ✡ ON MAP OF COAL FIELDS OF OHIO.
TEST HOLE EAST OF GALLIPOLIS, GALLIA, CO. O.
TEST HOLE S.E. OF ANTIQUITY LETART TWP. MEIGS, CO. O.
TEST HOLE BETWEEN ATHENS & MARIETTA IN DECATURE TWP., WASHINGTON, CO. O.
TEST HOLE S.E. OF BISHOPVILLE, HOMER TWP. MORGAN, CO. O.
TEST HOLE NEAR SAN TOY MONROE TWP. PERRY, CO. O.
TEST HOLE NEAR STELLA JACKSON TWP. VINTON CO.
TEST HOLE NEAR PLEASANT CITY VALLEY TWP. GUERNSEY, CO. O.
TEST HOLE SOUTHERN PART LONDONDERRY TOWNSHIP, GUERNSEY, CO. O.
TEST HOLE EAST OF BELMONT GOSHEN TWP., BELMONT, CO. O.
TEST HOLE NEAR ALLENDONIA, WASHINGTON TWP., BELMONT, CO., O.
RECORD of McCLAIN TEST Near Bellaire, Ohio. Edward Christman, Driller Sept. 6 1902. Frank A. Ray, E.M.
Pittsburg or No 8 Coal
DRILL HOLE No 2
Located Near SE Cor Frac. Lot No 55
Salem Twp., Washington Co., Ohio
on N.W. Chandler Farm.
Log of Hole Platted to Scale 1" = 20 Ft
Edward Christman, Driller
Wade H Horn, Inspector
Frank A. Ray Consulting Engr
Feb 19 1913.
DRILL HOLE No 1
Located Near NE Cor Frac. Lot 55.
Salem Twp. Washington Co. Ohio
Charles Shilling, Driller
Edward Christman Inspector
Frank A. Ray Consulting Engr
COAL No 8
MEIGS CREEK COAL



TEST HOLE S.E. OF BISHOPVILLE, HOMER TWP. MORGAN, CO. O.
TEST HOLE NEAR SAN TOY MONROE TWP. PERRY, CO. O.
TEST HOLE NEAR STELLA JACKSON TWP. VINTON CO. OHIO.
TEST HOLE NEAR PLEASANT CITY VALLEY TWP. GUERNSEY, CO. O.
GUERNSEY, CO. O.
TOP
SANDSTONE
RED SHALE
GREY SHALE
LIMESTONE
BLUE SHALE
SANDY SHALE
FIRE CLAY
COAL Nº 8
COAL Nº 7
COAL Nº 6
COAL Nº 5
BLACK SLATE
DARK SLATE
SANDY SLATE
GRIT ROCK
SOIL
BLUE CLAY
SAND
GRAVEL
SOIL SAND & GRAVEL
SHALE
NO COAL FOUND IN THIS INTERVAL
SALT SAND (BIG INJUN) 40'-0" THICK 785'-0" DEPTH.
BREA GRIT 81'-0" THICK WITH LAST 19'-0" PAY SAND
TOTAL DEPTH 1218 FEET.
WAVERLY SANDSTONE
BLACK SLATE WITH S.S. GAS
VERTICAL SCALE.
100 FT
80 FT
60 FT
40 FT
20 FT
10 FT.
LITTLE CLARKSBURG OR NORWICH OR 7 b COAL
GROFF OR BRUSH CREEK OR 7 a COAL
UPPER FREEPORT OR 7 COAL
MIDDLE KITTANNING OR Nº 6 COAL



Minable Coal Areas in Ohio.

Such conditions as these render it impossible to make an accurate estimate of Ohio coal reserve until the whole of its coal areas have been thoroughly prospected by mining and drilling, and the minable coal areas have all been definitely located.

PROVEN COAL AREA USED IN COAL RESERVE ESTIMATE.

(See Map, Page 28.)

The writer has located all of the important coal mines as nearly as possible on Dr. Orton's map of the Ohio Coal Fields, and has made use of these locations together with records of drilling to define the areas of proven coal. The probable unexplored coal area is in most cases all of the territory not covered by proven areas lying between the outcrop on the west and an arbitrary easterly and westerly line connecting the eastern extremities of proven fields.

The thickness of the coal used for the various fields represents the average measured sections of clean coal taken from the mines or from drilling records.

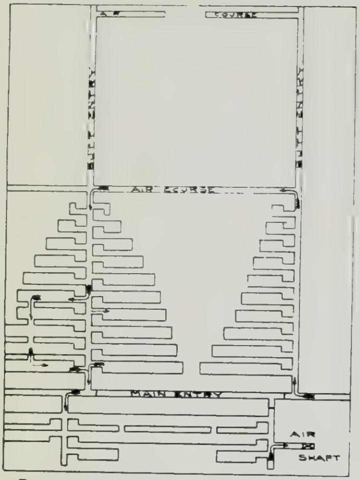
Fifteen hundred tons run of mine per vertical foot per acre have been used as a constant for all coal in estimating the tonnage. The writer has endeavored to be conservative and give the various fields full credit for all the coal the known facts will warrant.

LOSSES IN MINING.

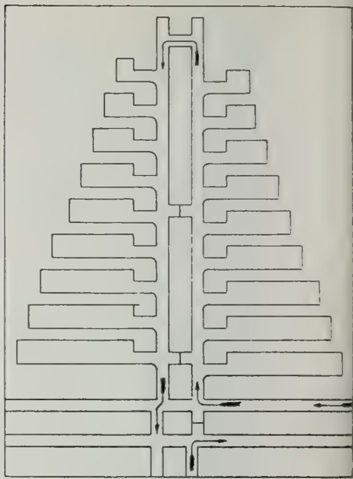
The amount of coal that has been lost in the process of mining in Ohio is a question of judgment about which there may be widely differing opinions. There is no doubt but that such losses were greater in the early days of Ohio mining than they are now with the present improved methods and systems of mining. A loss equal to 30% of the coal mined is assumed and added to the total coal produced, which should give the total coal depleted from the State.

COAL DEPLETION FOR OHIO.

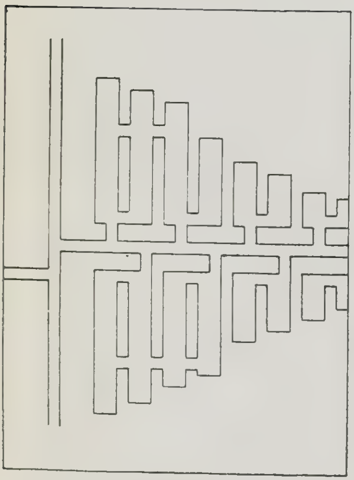
It is impossible to ascertain the actual amount of coal that has been mined in Ohio. Until 1872 no attempt was made to collect the statistics of the State's coal production. The early statistics give only the lump and nut coal produced, and even these are very incomplete. To all such figures have been added twenty per cent for pea and slack to bring the tonnage to run of mine coal. The earliest produc-



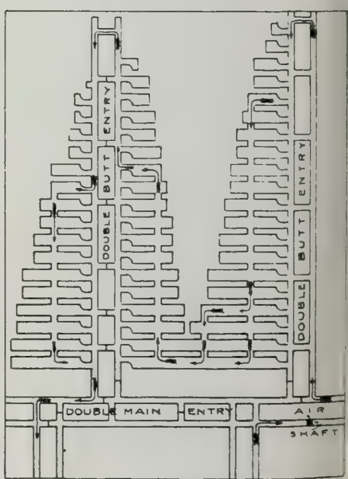
PLAN OF WORKING IN HOCKING VALLEY
SYSTEM OF MINING IN 1874
USED BY THE NELSONVILLE MINING CO.



DOUBLE ENTRY PLAN.
SYSTEM RECOMENDED IN 1876



PLAN.
SYSTEM OF MINING IN 1876.
USED BY STRAITSVILLE MINING CO.



PLAN OF WORKING
SYSTEM OF MINING IN 1876,
USED BY THE NEWARK COAL COMPAN
IN THEIR SHAWNEE MINES.

Early Systems of Mining in Ohio.

Illustrating a Poor System of Mining.


MAP
OF
PROPOSED MINE WORKINGS
REPUBLIC IRON & STEEL CO
REPUBLIC PA.

Prepared by

F. A. RAY, E. M.

PROFESSOR OF

Mine Engineering

School of Mines

Ohio State University

Columbus

1914

TOTAL AREA OF COAL MEASURES IN SQUARE MILES.	UNEXPLORED COAL AREAS. IN SQUARE MILES.	COUNTY	PROVEN MINABLE COAL IN SQUARE MILES.									
			Nº 8A COAL	Nº 8 COAL	Nº 7 COAL	Nº 6 THICK COAL	Nº 6 THIN COAL	Nº 5 COAL	Nº 4 COAL	Nº 3 COAL	Nº 2 COAL	Nº 1 COAL
AVERAGE THICKNESS CLEAN COAL			3.5	5.5	5.2	7.0	3.5	3.25	4.0	3.5	2.7	3.0
483		ATHENS		18	6	156	10					
478		BELMONT	270	415								
400	160	CARROLL			10		20	10				
510	830	COLUMBIANA			15		75			10		
480	90	COSHOCTON					92					
300	100	GALLIA		8				20	5			
442	140	GUERNSEY		10	90		60					
850		HARRISON	10	110	10							
215		HOCKING				31					3	
259		HOLMES					10					
375	30	JACKSON						40	4		25	
360		JEFFERSON		110			50					
400	130	LAWRENCE						50				
385	55	MAHONNING						8		5		
130		MEDINA										5
380	20	MEIGS		112								
550	800	MUSKINGUM			10		50					
372	141	NOBLE	5		15							
842		PERRY				37	133					
480		PORTAGE										5
890	90	STARK										8
880		SUMMIT										3
180		TRUMBULL										2
880	100	TUSCARAWAS			5		65	12				
538	65	VINTON						6	5	4	4	1
540		WASHINGTON					5					
155		WAYNE										5
831		MORGAN					92					
176		SCIOTO							2			
405		MONROE		14								
11396	1751	TOTAL	285	797	161	224	662	143	16	19	32	29

TAKEN FROM
THE COAL RESOURCES OF THE WORLD
VOLUME I PAGE XVIII.

ESTIMATE OF THE COAL RESERVES OF THE WORLD

NAMES OF COUNTRIES	TOTAL TONS COAL
OCEANIA	170,410,000,000
ASIA	1,279,586,000,000
AFRICA	57,839,000,000
NEW FOUNDLAND	500,000,000
CANADA	1,234,269,000,000
CENTRAL AMERICA	5,000,000
SOUTH AMERICA	32,097,000,000
EUROPE	784,190,000,000
UNITED STATES	3,838,657,000,000
TOTAL	7,397,553,000,000

ESTIMATED TONS BY COUNTIES OF PROVEN RUN OF MINE COAL ORIGINALLY CONTAINED BY THE VARIOUS MINABLE COAL SEAMS — THE TOTAL PRODUCTION TO 1913 — THE ESTIMATED TONS OF UNMINED COAL IN OHIO —

COUNTY	TONS OF RUN OF MINE COAL IN VARIOUS COAL SEAMS - OHIO -										TOTAL TONS R. OF M. COAL ALL KINDS.	TOTAL COAL PRODUCTION 1828 TO 1913.	TOTAL ESTIMATED REMAINING PROVEN COAL.
	Nº 8A SEAM	Nº 8 SEAM	Nº 7 SEAM	Nº 6 THICK SEAM	Nº 6 THIN SEAM	Nº 5 SEAM	Nº 4 SEAM	Nº 3 SEAM	Nº 2 SEAM	Nº 1 SEAM			
AVERAGE THICKNESS	3.5 FT.	5.5 FT.	5.2 FT.	7.0 FT.	3.5 FT.	3.25 FT.	4.0 FT.	3.5 FT.	2.7 FT.	3.0 FT.			
ATHENS		95,040,000	29,932,000	1,048,320,000	33,600,000						1,206,912,000	75,990,161	1,130,921,839
BELMONT	907,200,000	2,191,200,000									3,098,400,000	79,440,330	3,018,959,670
CARROLL			49,920,000		67,200,000	30,720,000					147,840,000	8,588,703	139,451,297
COLUMBIANA			74,880,000		252,000,000			33,600,000			360,480,000	19,083,897	341,396,103
COSHOCTON					309,120,000						309,120,000	8,385,394	300,734,606
GALLIA		42,240,000				61,440,000	19,200,000				122,880,000	530,840	122,349,160
GUERNSEY		52,800,000	449,280,000		201,600,000						703,680,000	52,538,894	651,141,106
HARRISON	33,600,000	580,800,000	49,920,000								664,320,000	5,301,289	659,018,711
HOCKING				208,320,000					7,776,000		216,096,000	43,328,103	172,767,897
HOLMES					33,600,000						33,600,000	508,300	33,091,700
JACKSON						122,880,000	15,360,000		64,800,000		203,040,000	43,591,740	159,448,260
JEFFERSON		580,800,000			168,000,000						748,800,000	51,773,178	697,026,822
LAWRENCE						153,600,000					153,600,000	4,429,822	149,170,178
MAHONING						15,360,000		16,800,000			32,160,000	4,307,158	27,852,842
MEDINA										14,400,000	14,400,000	4,228,163	10,171,837
MEIGS		451,584,000									451,584,000	9,767,920	441,816,080
MUSKINGUM			49,920,000		168,000,000						217,920,000	8,151,170	209,768,830
NOBLE	16,800,000		74,880,000								91,680,000	3,809,308	87,870,692
PERRY				248,640,000	446,880,000						695,520,000	60,754,657	634,765,343
PORTAGE										14,400,000	14,400,000	3,300,650	11,099,350
STARK										23,040,000	23,040,000	20,997,428	2,042,572
SUMMIT										8,640,000	8,640,000	3,088,303	5,551,697
TRUMBULL										5,760,000	5,760,000	2,077,722	3,682,278
TUSCARAWAS			24,960,000		218,400,000	36,864,000					280,224,000	27,696,452	252,527,548
VINTON						18,432,000	19,200,000	13,200,000	7,680,000	11,520,000	70,032,000	3,376,141	66,655,859
WASHINGTON					16,800,000						16,800,000	81,478	16,718,522
WAYNE										14,400,000	14,400,000	4,800,502	9,591,498
MORGAN					309,120,000						309,120,000	2,004,653	307,115,347
SCIOTO							300,000				300,000	178,414	121,586
MONROE		73,920,000									73,920,000	29,292	73,890,708
TOTALS	987,600,000	4,068,384,000	803,712,000	1,505,280,000	2,224,320,000	489,296,000	54,060,000	63,600,000	80,256,000	92,160,000	10,288,668,000	551,948,062	9,736,719,938
TOTAL PRODUCTION ALL COUNTIES 1828 TO 1883												ADD 109,956,583	LESS 109,956,583
ESTIMATED 30% LOSS IN MINING TOTAL COAL PRODUCED IN OHIO TO 1913												ADD 198,571,393	LESS 198,571,393
TOTAL TONS PROVEN COAL — TOTAL TONS EXHAUSTED COAL — TOTAL TONS PROVEN COAL REMAINING — 10,288,668,000												860,476,038	9,428,191,962

COUNTIES SLIGHTLY EXPLORED	→ RECAPITULATION —
GALLIA	PROBABLE TONS COAL IN 1751 SQ. MILES UNEXPLORED AREA....4,000,000,000
WASHINGTON	TOTAL TONS PROVEN COAL REMAINING..........9,428,191,962
MONROE	TOTAL TONS ESTIMATED OHIO COAL RESERVE..........13,428,191,962

tion statistics obtainable for this publication begin with 1828, which is probably at or near to the beginning of the Ohio coal production. The earliest production statistics of counties begin in 1883, and have been collected and published in the reports of the Chief Mine Inspector.

The Chart page shows the tabulated results of the writer's estimate of Ohio proven minable coal. It is estimated that there is at least 1731 square miles of unexplored probable coal area. In this estimate it is assumed that 80 per cent. of this area contains one minable seam of coal three feet thick. This estimated quantity is added to the amount of proven coal tonnage. In four of the most important districts these estimates are compared with the estimates made by well-known mining engineers employed in these districts. In each instance the writer's estimates have been somewhat larger.

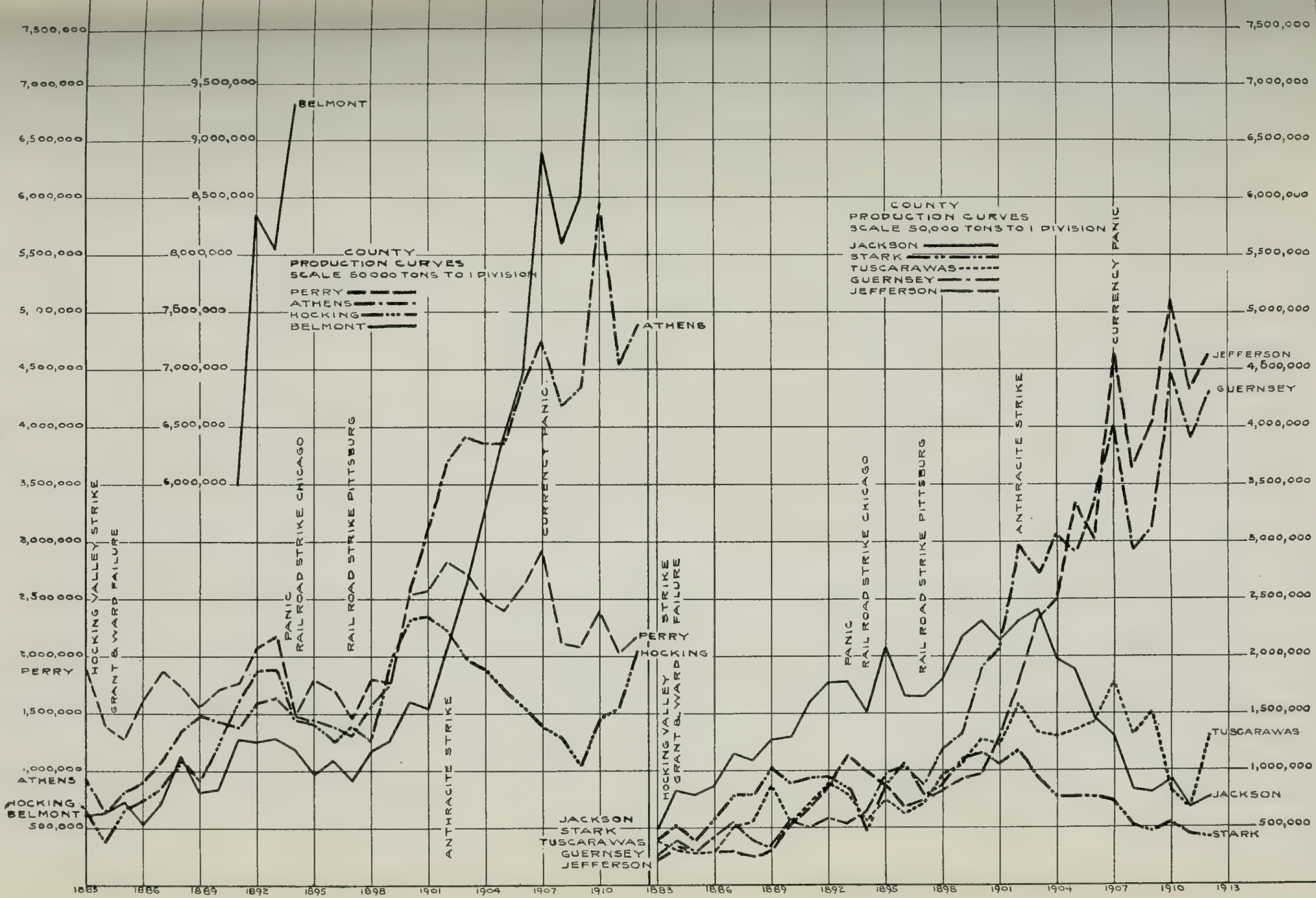
On this basis the total Ohio coal reserve amounts to 13,428,000.000 tons, or enough to fill a train of 50-ton cars long enough to reach 73 times around the earth. Yet this amounts to little more than one-sixth of Mr. M. R. Campbell's estimate of Ohio coal reserve.

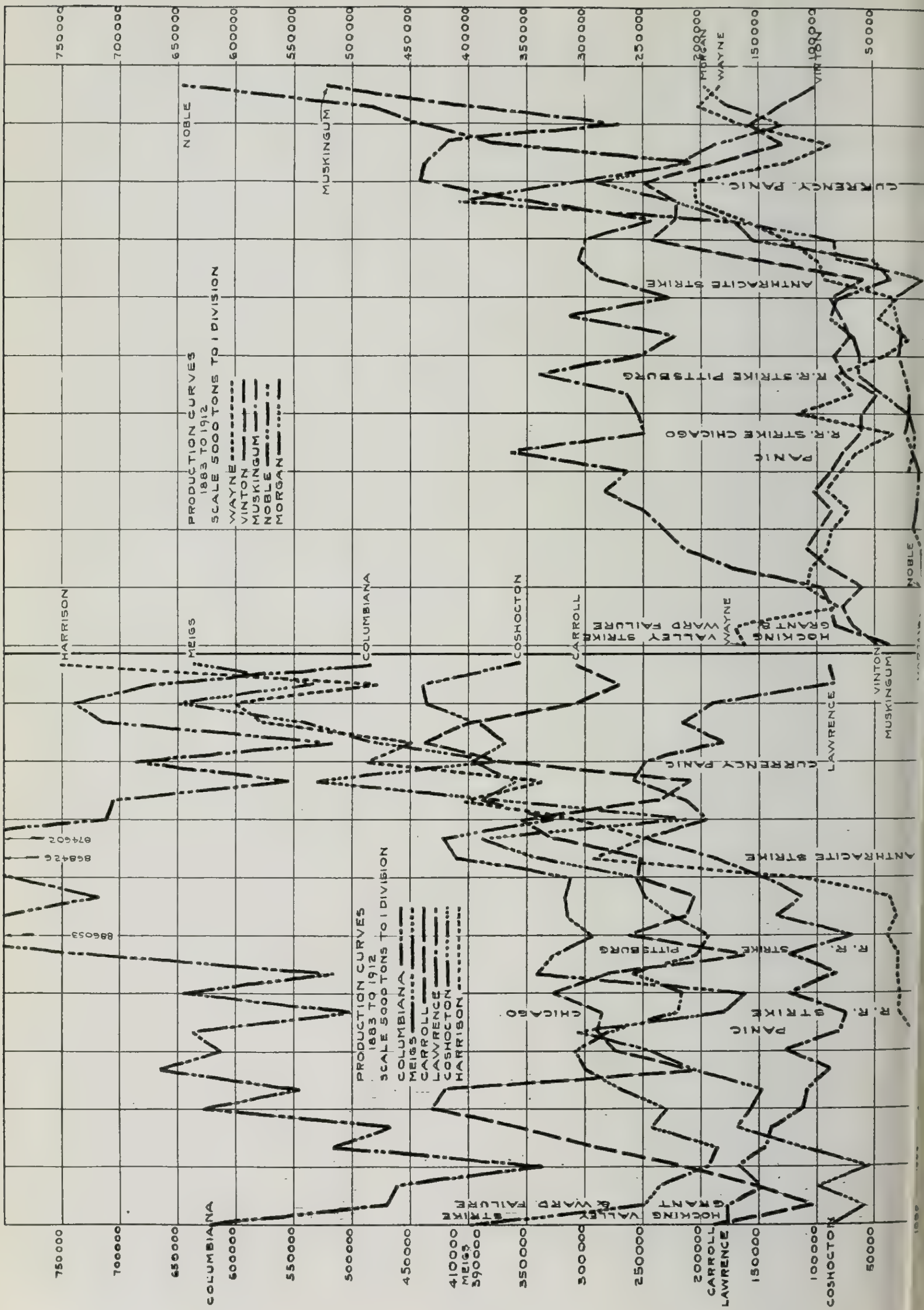
DEPLETION CURVES.

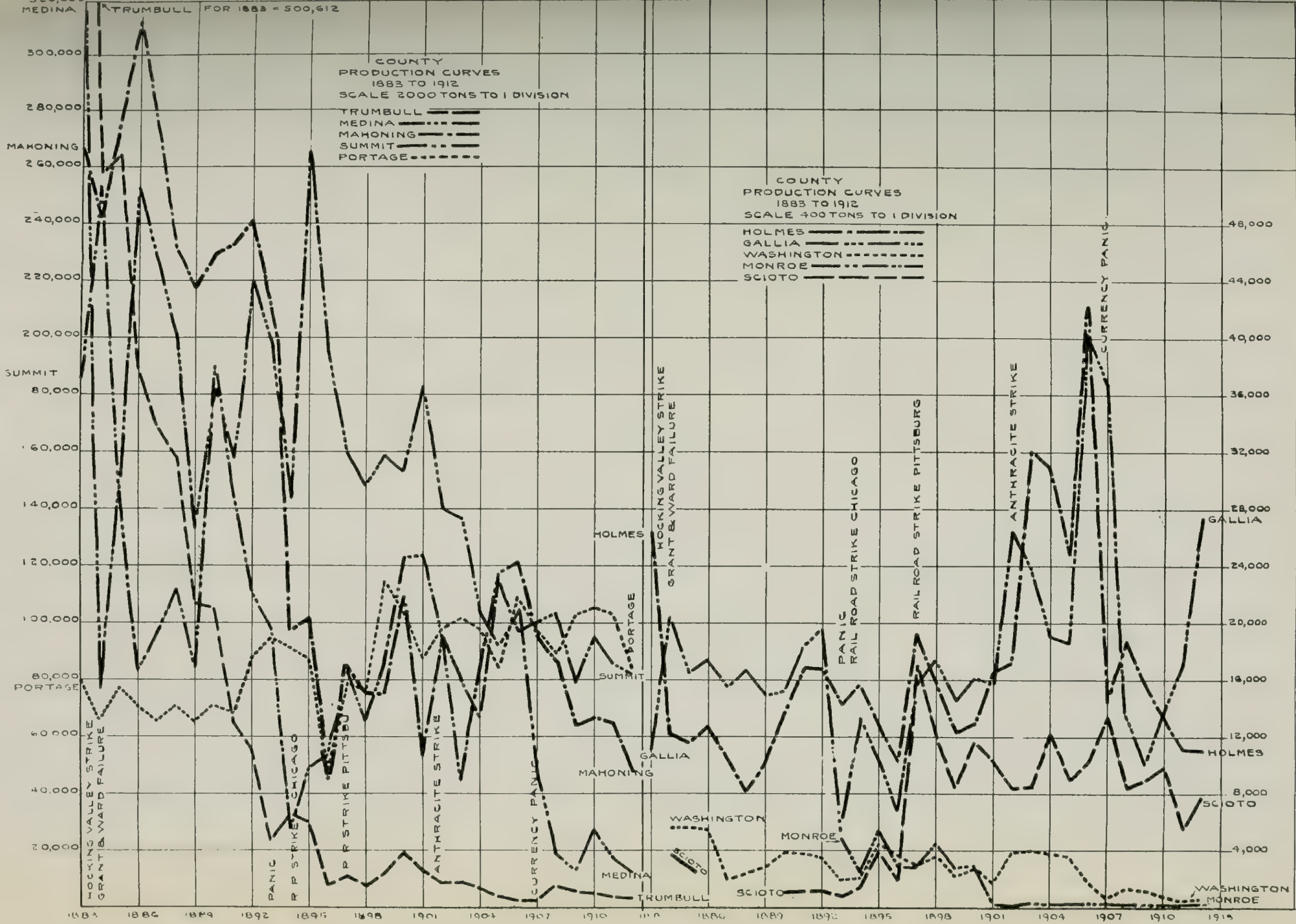
With the object of studying the depletion of coal areas, the writer has platted the annual production curves of the counties for the years 1883 to 1912, inclusive. Three distinct types of curves are developed which indicate three classes of coal producing counties: those in which the annual production was at its maximum at the beginning of the curve and gradually became less; those counties which began small and increased year by year to the maximum, holding that for several years, then gradually lessening in production to the end of the curve. The third class is for counties whose annual production has not yet reached the maximum.

The typical curves indicate to some extent the degree of exhaustion of the coal fields. None of the Ohio districts have been actively productive for more than fifty years, and yet most of them begin to show a decline and some of them show decided symptoms of exhaustion.

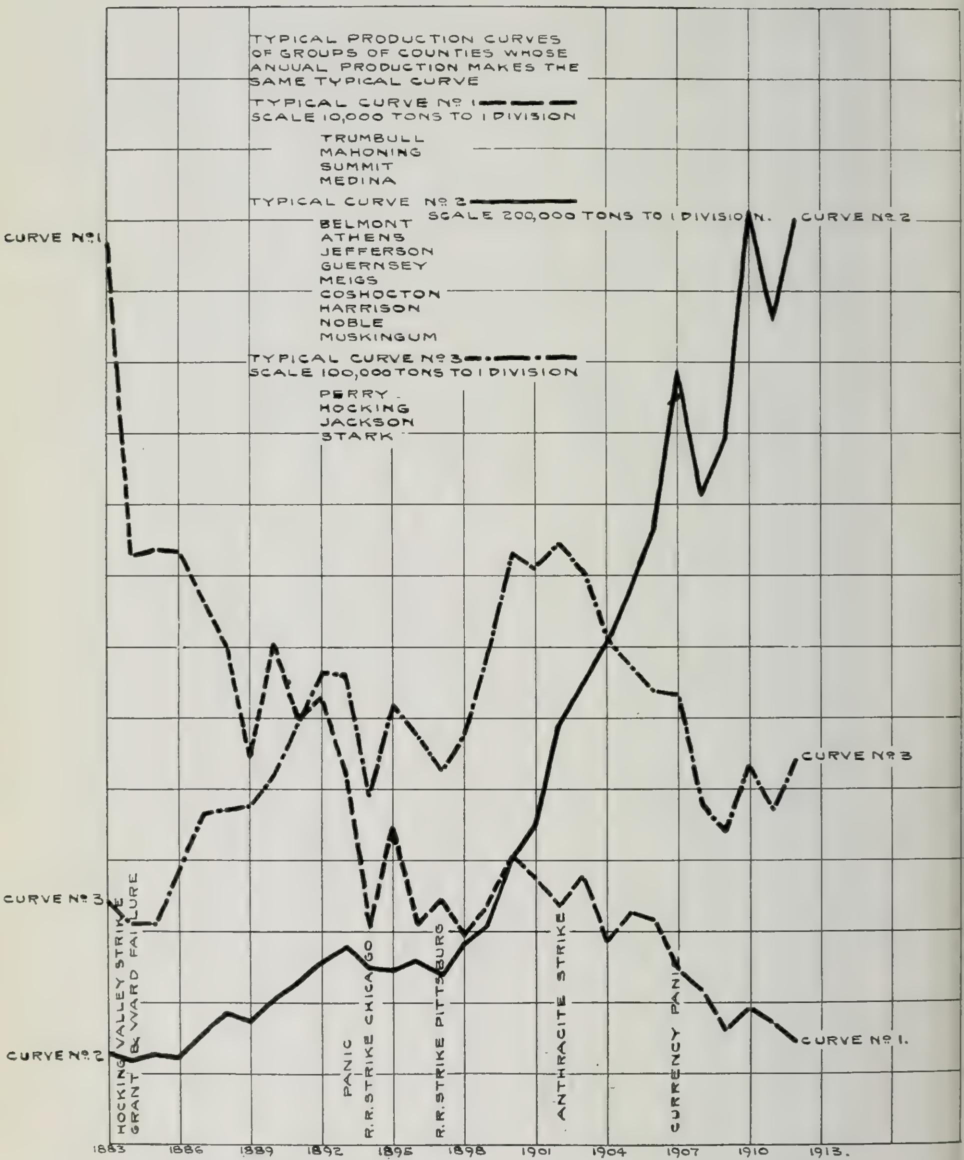
With the knowledge that our coal supply is definite and that its depletion is going on with increasing rapidity, we naturally inquire if there are not practical ways of conservation by the stopping of mining losses. The present average loss in mining in Ohio amounts to 30 per cent, excluding defective coal that is left in the mine and usually lost.


COUNTY
PRODUCTION CURVES
SCALE 50,000 TONS TO 1 DIVISION
PERRY
ATHENS
HOCKING
BELMONT
JACKSON
STARK
TUSCARAWAS
GUERNSEY
JEFFERSON
HOCKING VALLEY STRIKE
GRANT & WARD FAILURE
PANIC
RAIL ROAD STRIKE CHICAGO
RAIL ROAD STRIKE PITTSBURG
ANTHRACITE STRIKE
CURRENCY PANIC
7,500,000
7,000,000
6,500,000
6,000,000
5,500,000
5,000,000
4,500,000
4,000,000
3,500,000
3,000,000
2,500,000
2,000,000
1,500,000
1,000,000
500,000
9,500,000
9,000,000
8,500,000
8,000,000
7,500,000
7,000,000
6,500,000
6,000,000
1883
1886
1889
1892
1895
1898
1901
1904
1907
1910
1913

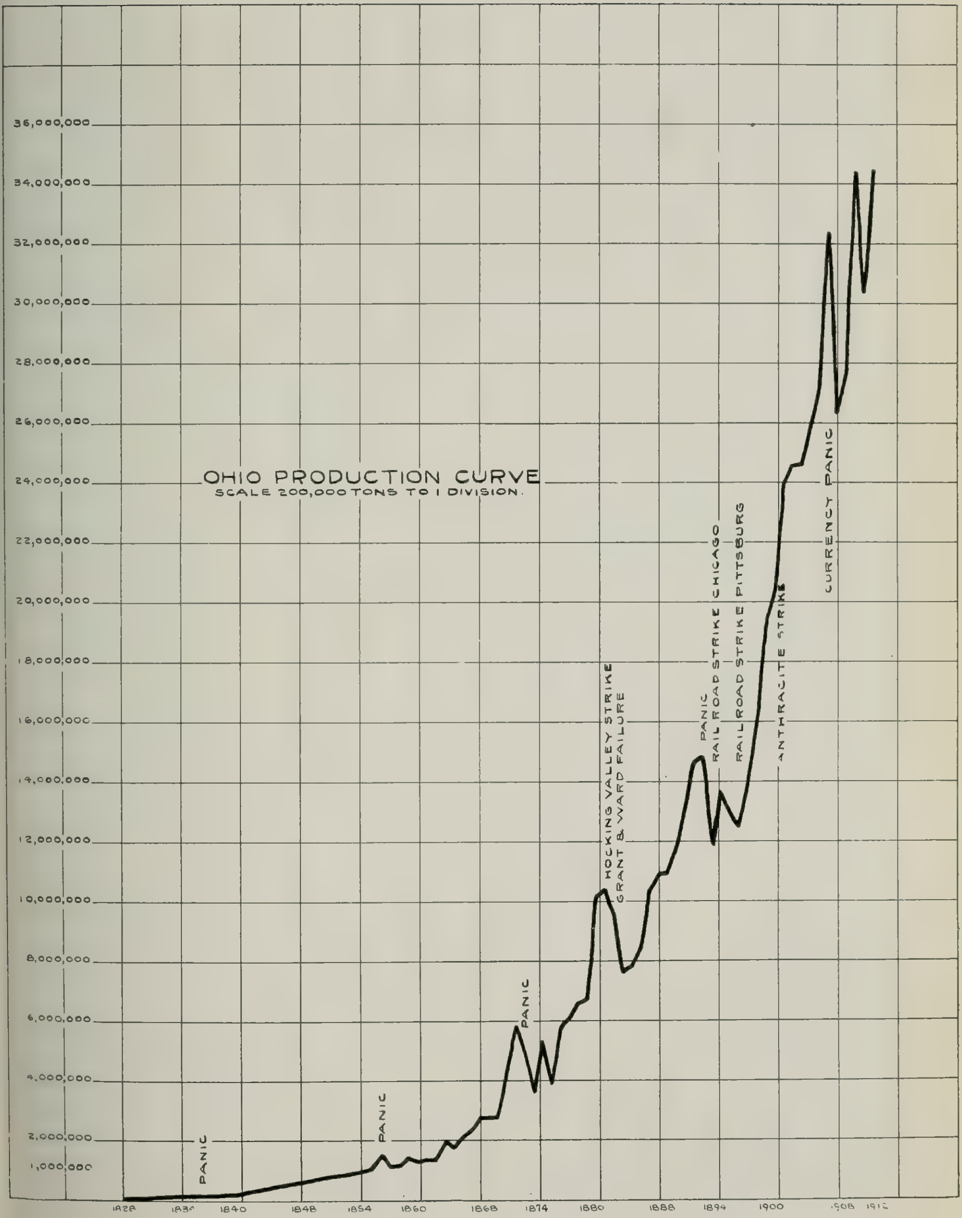

PRODUCTION CURVES
1883 TO 1912
SCALE 5000 TONS TO 1 DIVISION
WAYNE
VINTON
MUSKINGUM
NOBLE
MORGAN
PRODUCTION CURVES
1883 TO 1912
SCALE 5000 TONS TO 1 DIVISION
COLUMBIANA
MEIGS
CARROLL
LAWRENCE
COSHOCTON
HARRISON
HOCKING VALLEY STRIKE
GRANT & WARD FAILURE
PANIC
R.R. STRIKE CHICAGO
R.R. STRIKE PITTSBURG
ANTHRACITE STRIKE
CURRENCY PANIC
NOBLE
MUSKINGUM
MORGAN
WAYNE
VINTON
COLUMBIANA
MEIGS
CARROLL
LAWRENCE
COSHOCTON
HARRISON
886053
868426
874602



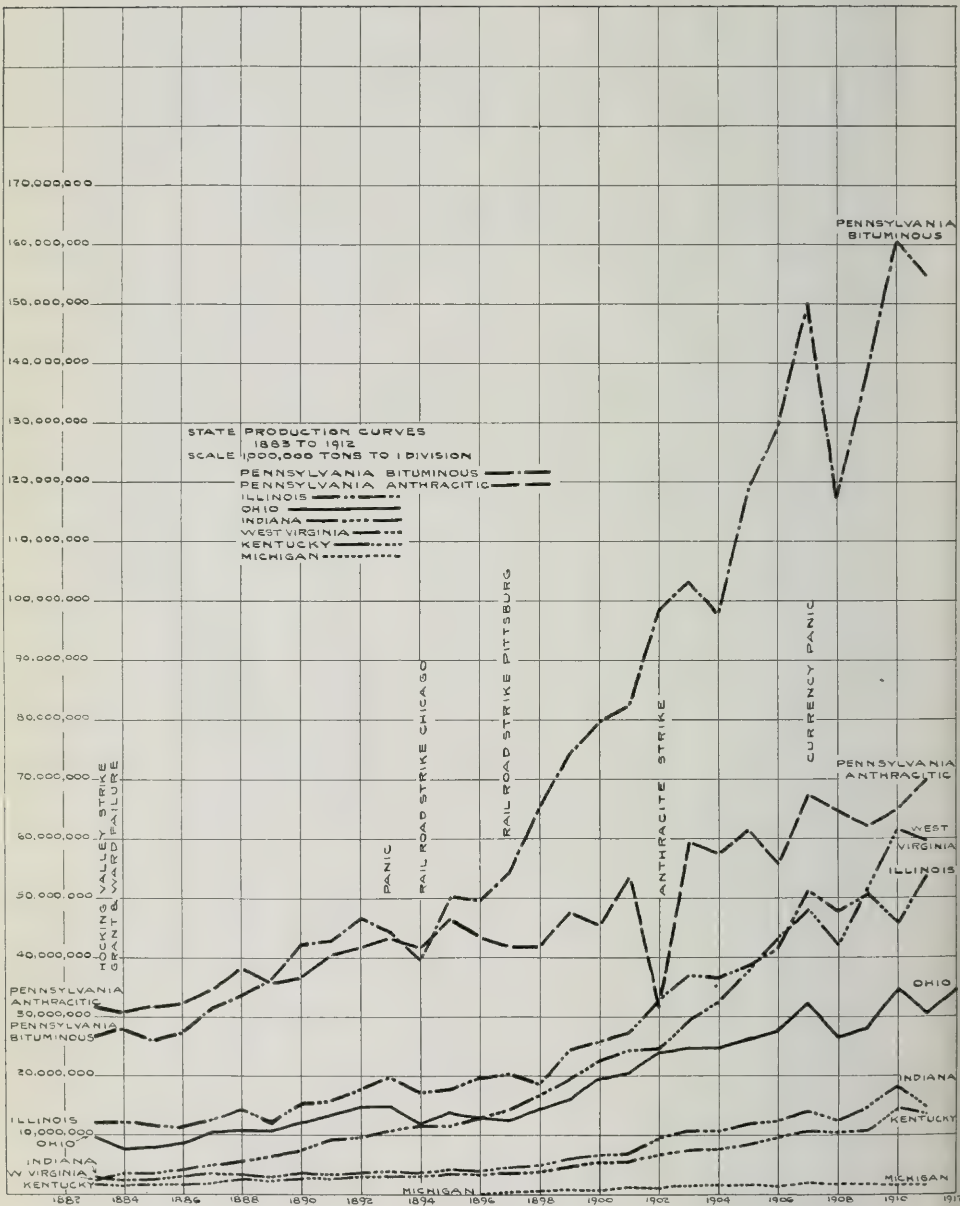
MEDINA
TRUMBULL FOR 1883 = 500,612
COUNTY
PRODUCTION CURVES
1883 TO 1912
SCALE 2000 TONS TO 1 DIVISION
TRUMBULL
MEDINA
MAHONING
SUMMIT
PORTAGE
COUNTY
PRODUCTION CURVES
1883 TO 1912
SCALE 400 TONS TO 1 DIVISION
HOLMES
GALLIA
WASHINGTON
MONROE
SCIOTO
300,000
280,000
MAHONING
260,000
240,000
220,000
200,000
SUMMIT
80,000
160,000
140,000
120,000
100,000
80,000
PORTAGE
60,000
40,000
20,000
48,000
44,000
40,000
36,000
32,000
28,000
24,000
20,000
16,000
12,000
8,000
4,000
HOCKING VALLEY STRIKE
GRANT & WARD FAILURE
PANIC
R R STRIKE CHICAGO
R R STRIKE PITTSBU
ANTHRACITE STRIKE
CURRENCY PANIC
PORTAGE
SUMMIT
HOLMES
GALLIA
MAHONING
MEDINA
TRUMBULL
HOCKING VALLEY STRIKE
GRANT & WARD FAILURE
WASHINGTON
SCIOTO
MONROE
PANIC
RAIL ROAD STRIKE CHICAGO
RAIL ROAD STRIKE PITTSBURG
ANTHRACITE STRIKE
CURRENCY PANIC
GALLIA
HOLMES
SCIOTO
WASHINGTON
MONROE
1883
1886
1889
1892
1895
1898
1901
1904
1907
1910
1886
1889
1895
1898
1901
1904
1907
1910



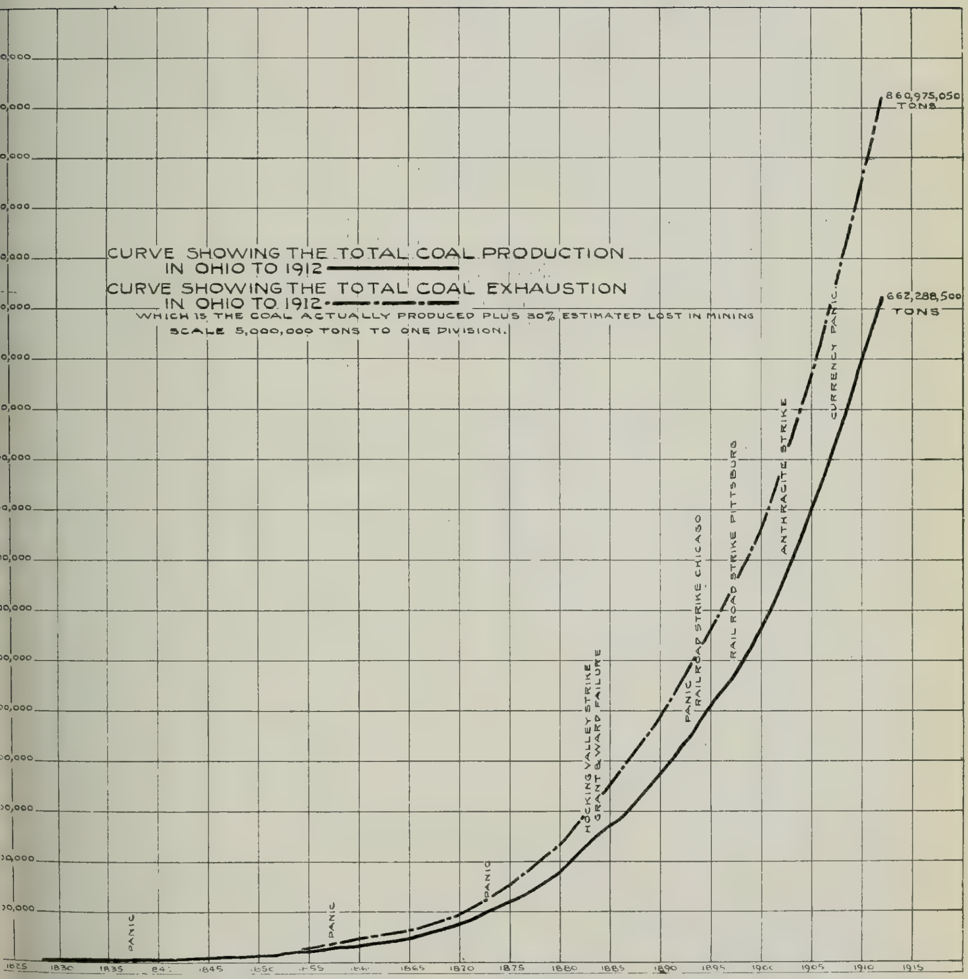
TYPICAL PRODUCTION CURVES
OF GROUPS OF COUNTIES WHOSE
ANUUAL PRODUCTION MAKES THE
SAME TYPICAL CURVE
TYPICAL CURVE Nº 1
SCALE 10,000 TONS TO 1 DIVISION
TRUMBULL
MAHONING
SUMMIT
MEDINA
TYPICAL CURVE Nº 2
SCALE 200,000 TONS TO 1 DIVISION.
BELMONT
ATHENS
JEFFERSON
GUERNSEY
MEIGS
COSHOCTON
HARRISON
NOBLE
MUSKINGUM
TYPICAL CURVE Nº 3
SCALE 100,000 TONS TO 1 DIVISION
PERRY
HOCKING
JACKSON
STARK
CURVE Nº 1
CURVE Nº 2
CURVE Nº 3
CURVE Nº 3
CURVE Nº 2
CURVE Nº 1.
HOCKING VALLEY STRIKE
GRANT & WARD FAILURE
PANIC
R.R. STRIKE CHICAGO
R.R. STRIKE PITTSBURG
ANTHRACITE STRIKE
CURRENCY PANIC
1883
1886
1889
1892
1895
1898
1901
1904
1907
1910
1913.



OHIO PRODUCTION CURVE
SCALE 200,000 TONS TO 1 DIVISION.
36,000,000
34,000,000
32,000,000
30,000,000
28,000,000
26,000,000
24,000,000
22,000,000
20,000,000
18,000,000
16,000,000
14,000,000
12,000,000
10,000,000
8,000,000
6,000,000
4,000,000
2,000,000
1,000,000
PANIC
PANIC
PANIC
HOCKING VALLEY STRIKE
GRANT & WARD FAILURE
PANIC
RAIL ROAD STRIKE CHICAGO
RAIL ROAD STRIKE PITTSBURG
ANTHRACITE STRIKE
CURRENCY PANIC
1828
1840
1848
1854
1860
1868
1874
1880
1888
1894
1900
1908



STATE PRODUCTION CURVES
1883 TO 1912
SCALE 1,000,000 TONS TO 1 DIVISION
PENNSYLVANIA BITUMINOUS
PENNSYLVANIA ANTHRACITIC
ILLINOIS
OHIO
INDIANA
WEST VIRGINIA
KENTUCKY
MICHIGAN
170,000,000
160,000,000
150,000,000
140,000,000
130,000,000
120,000,000
110,000,000
100,000,000
90,000,000
80,000,000
70,000,000
60,000,000
50,000,000
40,000,000
30,000,000
20,000,000
10,000,000
HOCKING VALLEY STRIKE
GRANT & WARD FAILURE
PANIC
RAIL ROAD STRIKE CHICAGO
RAIL ROAD STRIKE PITTSBURG
ANTHRACITE STRIKE
CURRENCY PANIC
1882
1884
1886
1888
1890
1892
1894
1896
1898
1900
1902
1904
1906
1908
1910
1912


CURVE SHOWING THE TOTAL COAL PRODUCTION IN OHIO TO 1912
CURVE SHOWING THE TOTAL COAL EXHAUSTION IN OHIO TO 1912
WHICH IS THE COAL ACTUALLY PRODUCED PLUS 30% ESTIMATED LOST IN MINING
SCALE 5,000,000 TONS TO ONE DIVISION.
860,975,050 TONS
662,288,500 TONS
PANIC
PANIC
PANIC
HOCKING VALLEY STRIKE
GRANT & WARD FAILURE
PANIC
RAILROAD STRIKE CHICAGO
RAIL ROAD STRIKE PITTSBURG
ANTHRACITE STRIKE
CURRENCY PANIC
1830
1835
1845
1865
1870
1875
1880
1885
1890
1895
1905
1910
1915

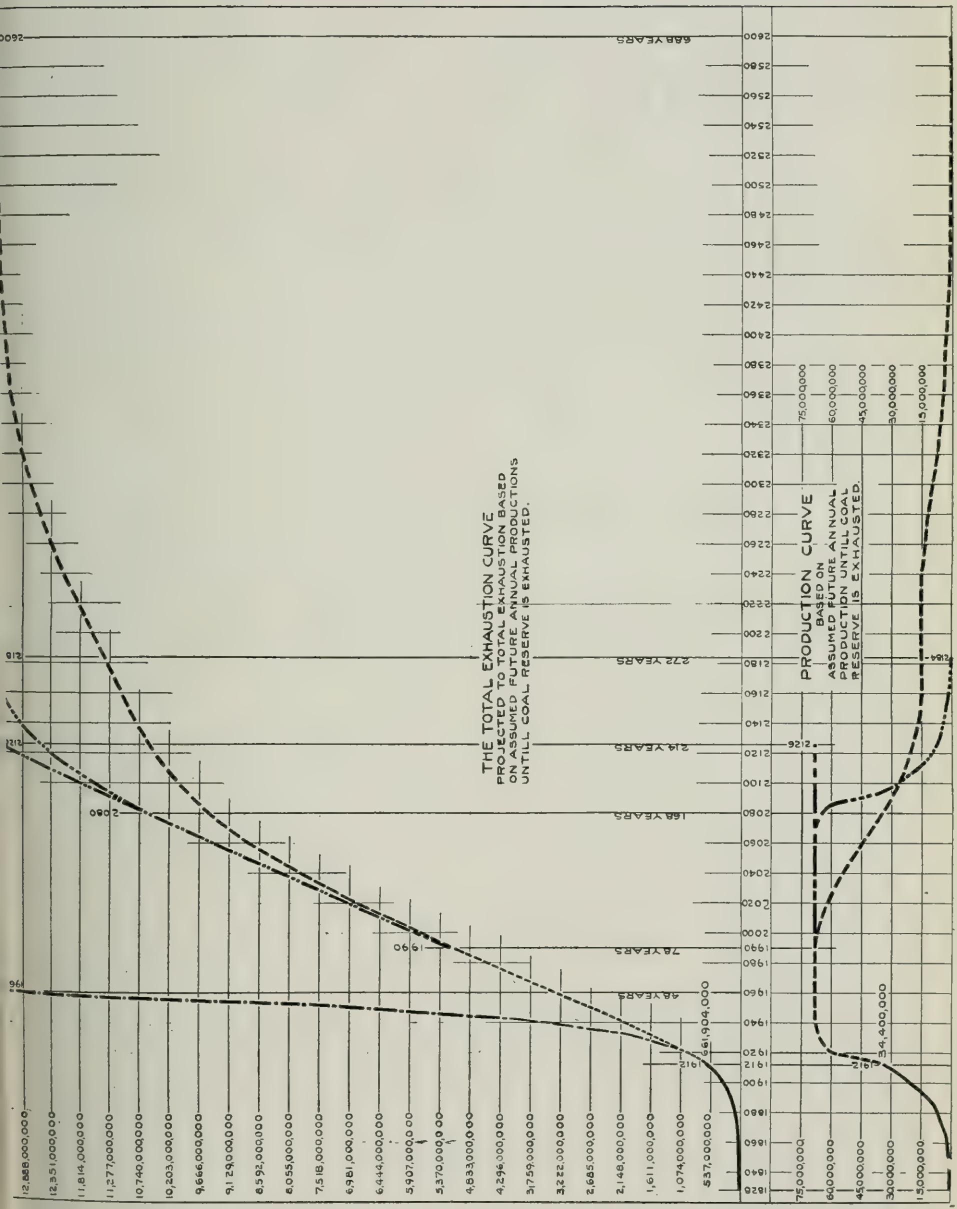
This loss could be materially reduced by raising the standards of competency of all engaged in mining coal, by employing more efficient systems and methods of mining. The necessary loss in mining ought not to exceed 15 per cent. of the minable coal. If this be true the unnecessary loss is 15 per cent and could be saved.

Unfortunately the attention of the public has been called to this one item of waste to the exclusion of all others. J. M. Searle, Chief of the Division of Smoke Inspector of Pittsburg, Pennsylvania, says that the unnecessary loss in the use of coal in Pittsburg is 20 per cent, an unnecessary loss for 1912 amounting to 1,121,283 tons, or $1,151,-283.00 for Pittsburg alone. This amount of unnecessary loss in the use of coal will undoubtedly hold true for the whole of the United States. The ordinary thermal efficiencies of main power units range from 15 to 33 per cent, which entails a loss in fuel consumed of 67 to 85 per cent. Should we not direct our efforts towards securing more efficient results in the use of coal?

HOW LONG WILL OUR COAL LAST?

No one can predict the time when Ohio's coal reserve will be exhausted. I have prepared the curve page 39, which accurately shows what has taken place in annual production and total depletion from the beginning of coal production in Ohio to 1912. The total exhaustion curve shows that the annual production has in the past nearly doubled every ten years. See curve page 41. If this rate of increase should continue until total depletion, the coal will be exhausted in 48 years, which means at the end the annual production would have to be over 600,000,000 tons. See curve page 43. This rate of increase cannot go on indefinitely. There must come a time when the output of coal for Ohio will be reduced to its natural markets only, and the annual production will then remain practically constant up to the time of beginning decline, when the annual production will grow gradually less and finally cease when total exhaustion is reached.

If the annual output is allowed to double for the next ten years and then remain constant until the end, total exhaustion would be reached in 214 years. If this constant production were allowed to continue for 168 years, and the production on the declining side of the curve were the same as the beginning side, then the total depletion would be reached in 272 years. If the total exhaustion curve is platted from the assumed annual production curve shown, then the total depletion will be reached in 688 years. The total depletion will probably


THE TOTAL EXHAUSTION CURVE
PROJECTED TO TOTAL EXHAUSTION BASED ON ASSUMED FUTURE ANNUAL PRODUCTIONS UNTILL COAL RESERVE IS EXHAUSTED.
PRODUCTION CURVE
BASED ON ASSUMED FUTURE ANNUAL PRODUCTION UNTILL COAL RESERVE IS EXHAUSTED.
688 YEARS
272 YEARS
214 YEARS
168 YEARS
78 YEARS
48 YEARS
661,904,000
34,400,000
12,888,000,000
12,351,000,000
11,814,000,000
11,277,000,000
10,740,000,000
10,203,000,000
9,666,000,000
9,129,000,000
8,592,000,000
8,055,000,000
7,518,000,000
6,981,000,000
6,444,000,000
5,907,000,000
5,370,000,000
4,833,000,000
4,296,000,000
3,759,000,000
3,222,000,000
2,685,000,000
2,148,000,000
1,611,000,000
1,074,000,000
537,000,000
75,000,000
60,000,000
45,000,000
30,000,000
15,000,000

be reached at some time before this extreme, unless our unexplored coal areas develop bodies of coal that are now unknown to us, and more efficient substitutes for coal are discovered.

All of this is pure speculation. Our knowledge is yet deficient. We must know more of the facts, both as to the coal reserve and the future consumption, before the date of total depletion of the Ohio coal reserve can be predicted.

Dr. Orton in a tribute to what the coal miners have done for geology said: "I have to believe that much that we have already gained is solid knowledge; that is, firmly fixed no more to move, but no one sees more clearly than I how fragmentary and incomplete it all is after all."

CONTENTS.

THE OHIO STATE UNIVERSITY BULLETIN

Vol. XIX No. 7

The Hardwood Distillation Industry in America

EDWARD H. FRENCH AND JAMES R. WITHROW

BULLETIN No. 13
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The Hardwood Distillation Industry in America

BY EDWARD H. FRENCH AND JAMES R. WITHROW

The Hardwood Distillation Industry in America*

BY EDWARD H. FRENCH AND JAMES R. WITHROW

In view of the economic importance of the utilization of wood waste, and the increasing interest being manifested in this utilization, it naturally surprises the inquirer that there is practically no literature upon this industry from the point of view of actual American practice. It may not be without value, therefore, to consider the progress made in hardwood distillation and to trace its development from its inception in this country. We have gathered together consequently and classified much of the information which we have acquired in the plants of this industry during an experience in it totalling about twenty-five years.

This tracing of the development of an industry of the magnitude of this one is peculiarly interesting to the engineer, since it shows the necessarily slow evolution of the industry in the hands of the unscientific manipulator, and serves not only to emphasize the advantages possessed by the modern chemical engineer but also to indicate how much more rapid the development might have been in the hands of experienced chemical engineers. It indicates also that in the future, under the direction of the competent engineer, important advances may be made much more rapidly than in the past. This latter statement is significant when it is remembered that the advances made thus far have been due either to accidents or very often to workmen endeavoring to minimize the laboriousness of their work. As plants are operated on 12-hour shifts, this desire to economize energy may be readily understood.

For much of the historical information collected we desire to express our appreciation to Mr. Robert Mackay, who has been active in this industry for so many years. In fact, during the past fifteen years our own continued intimate acquaintance with Mr. Mackay has

*A paper read before the Philadelphia meeting of the American Institute of Chemical Engineers on December 4, 1914. Reprinted from Metallurgical & Chemical Engineering, vol. XIII, p. 30 (January, 1914).

been not only of unusual pleasure but of continuous instruction. A history of this industry would be incomplete without mention of the fact, that due largely to his personality and integrity, the firm with which Mr. Mackay is identified, has had the unusual experience, in an extensive industry, of supplying engineering materials for every plant of this nature in the United States and Canada with perhaps two exceptions, for a period covering the past 25 years.

Early History

While charcoal burning was doubtless carried on in the earliest days in this country it was not until 1830 that James Ward began the manufacture of pyroligneous acid, at North Adams, Mass., according to Monroe and Chatard (12th Census, United States, Bull. No. 210, Chemicals and Allied Products, p. 34). No claim is made that the pyroligenous acid was carried further, though it may have been. We have ourselves no information on this matter other than the above citation. As far as we can ascertain it was not until 1852 that works in the modern sense were inaugurated for the distillation of wood for the production of volatile products, and their semi-refined products. This does not appear in agreement with W. L. Rowland (Special agent 10th U. S. Census on Chemical Products and Salt, p. 23) who is later cited by Monroe and Chatard (Ibid) and C. L. Campbell, METALLURGICAL AND CHEMICAL ENGINEERING, 1910, p. 155, all of whom state that the manufacture of acetate of lime and methyl alcohol was started in the United States about 1867 by James A. Emmons and A. S. Saxon in Crawford County, Pa. Our information in this case comes from various manufacturers who have been in this business from the earliest times or at least whose family connection with it goes back to the beginning. One of these sources is Mr. Neil Patterson, whose father was in charge of the original "Scotch Works," built in 1852. In this year The Turnbull Company of Glasgow, Scotland, who were engaged there in the copper and iron industry as well as that of wood distillation, built the first operation in this country, by way of expanding their old country business. The place chosen for this location was known as Milburn, New York, now Conklins Station, on the D., L. & W. R. R. not far from Binghamton.*

*Mr. J. L. Stuart, of Corbett & Stewart, one of the earliest firms in this business in this country, informs us that the date 1852, given by Mr. Patterson for the building of the Turnbull plant, should be 1849.

This Turnbull company brought with them their apparatus as well as men experienced with their methods. On account of these Scotch workmen the works became known as the "Scotch Works" and this name has clung to it to the present time, although the original workmen gradually went with new operations which started shortly after this one. They had much to do with the subsequent expansion of the industry, all of them being later in charge of new works.

It is interesting to note in connection with this first plant that it was a type that was copied in detail in

FIG. 1—TYPICAL WOOD YARD IN PENNSYLVANIA

the construction of those that followed, for many years afterward. All these plants were equipped with cast-iron cylinders 42 in. in diameter and 9 ft. long, set in pairs, thus each pair held about 1¼ cords of wood. The wood was cut 7 ft. long and the charge "run off" every 12 hours, and six days a week. The stills and pans were operated during these early days exclusively by direct firing. The fuel used for the retorts, stills and pans was the charcoal produced, over which was poured the residual tar to make a quick fire.

This original works was followed in 1865 by Emmons & Co., of Brookdale, N. Y. In 1868 Alonzo Smith started a plant at Sturroco, Pa.; Keery Brothers, Cadosia; Mandaville, Emmons, Corbett & Mitchell, Livingston Manor, N. Y.; King & Co., Acidalia, N. Y.; Hilton &

Co., Hiltonville, N. Y.; Brandt & Schlager; Finch & Ross; Tyler & Hall; Inderlied & Co.; Bayless & Berkalue and Wright & Co. were also early in the field.

During the early part of this period of development the chief product desired was acetate of lime, for which from 12 to 15 cents per pound was obtained. The alcohol demand was almost negligible, that which was made was of very inferior quality and was kept in barrels, and most of it was lost by evaporation or through some "illegal vent." The charcoal also had but little commercial value and was largely consumed as fuel at the works,

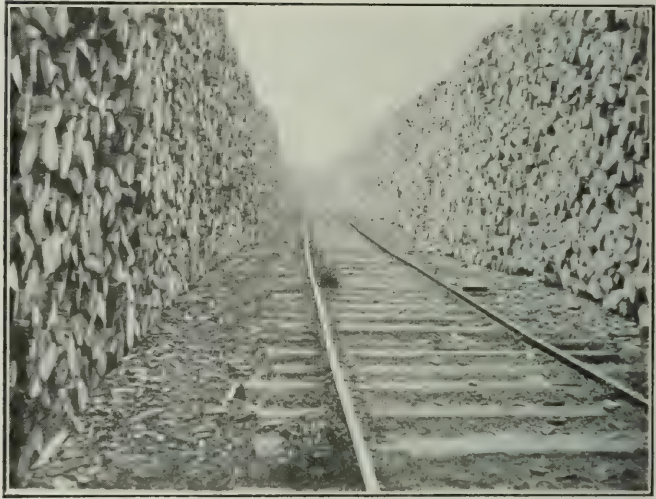

FIG. 2—CLOSE VIEW OF WOOD YARD

although a small local demand gradually developed starting with the neighborhood tinsmith.

The change from the old charcoal heaps or pits to the kilns probably came quite early and perhaps before any of the improvements we have mentioned. It was not until 1876, after the retort system was well established and markets for its products had been developed, however, that Dr. H. M. Pierce's inventions made it possible to utilize partially the products wasted in the smoke from the charcoal kilns in Michigan, where great quantities of charcoal were prepared for blast furnace use.

The earliest attempt at refining alcohol, so that it might be of commercial value, was made by a Mr. Pollock, a chemist living just out of New York City. In a short time a demand began to develop for this product,

which steadily increased, and up until 1880 was at all times up to the dollar mark. It was during this period that the need of better refining was felt, as it was realized that a large loss was entailed in the refining operations. This necessity accounts for the coming of the Burcey pans in the early seventies. These are copper containers placed in the vapor line above the stills, with deflectors inside to project the vapor against the upper shell of the container, upon which a stream of water runs, causing fractional separation of the water from the alcohol vapor. The increase of alcohol product resulting from this improvement, together with the increasing market demand, made a central refinery necessary, and the producers united in building a refinery at Binghamton, N. Y., known as the Burcey Refining Company. This was in the middle seventies, and the plant is still in operation. It has served a good purpose, and to it was due perhaps more than to anything else the substitution of steam for direct fire distillation.

Before leaving this early history, it should be mentioned that the Turnbull plant, and, in fact, several succeeding plants, had but four pairs of retorts or 5 cords capacity to the charge, thus by obtaining two charges within twenty-four hours there total wood consumption was about 10 cords per day. To-day there are single plants operating 160 cords daily. Thus we have an illuminating comparison, at least so far as size is concerned, of the development of the industry.

Design of Apparatus

Even at the present time there remain many plants using the old original retort system, with one every slight modification. Those first in service were of cast iron, while the later ones have shells of steel with riveted cast-iron necks and fronts. The purpose of this change was due to the fact that in the early operations, since the wood was then of much less value than later, and high yields were not so important, it was charred at a very high temperature, in order to increase as much as possible the capacity of the plant by shortening the time of firing. As cast iron was much more durable for these high temperatures than steel, the use of cast-iron retorts was universally practiced. When, however, with the coincident rise in the cost of wood, it was found that lower temperatures gave an increase of all products, it was seen that steel could be employed to advantage, for its lower weight permitted the turning of the retort. This turning refers to the saving in appa-

ratus universally practiced and consists merely in the removal of the brick setting when the side in contact with the fire becomes buckled, rolling over the retort, and placing the uninjured part next the fire, thus materially increasing the life of the retort. This modern retort is of uniform size and design in all plants which still use this type of apparatus. The shell, as originally, is 42 in. in diameter and 9 ft. long, supported at the ends in a cast-iron cradle and having a cast-iron front, with door and lugs for pinning the door shut. At the rear is a neck 10 in. in diameter with attached condenser.

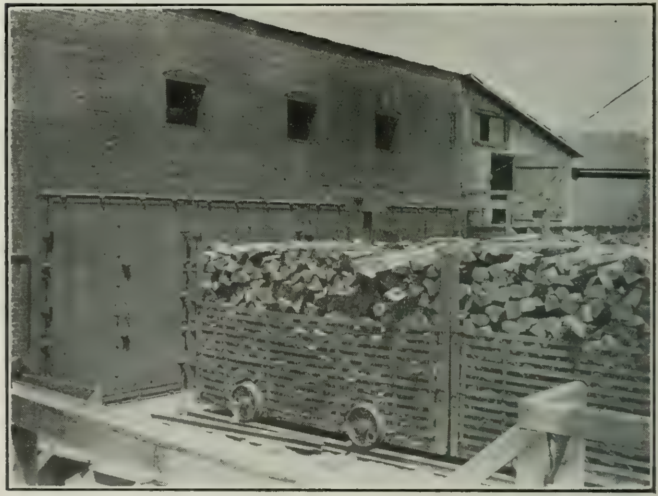

FIG. 3—LOADED WOOD CARS AT OVEN

The evolution of the condenser is especially interesting, in view of the fact that when the original condenser was installed each succeeding plant accepted it as being of proper size, and the new installation was made the same size. Then from time to time some one would discover that an addition would yield more product and at once the arbitrary sized unit was changed. Originally the worm condenser was used, but it soon became apparent that the heavy carbon bodies caused clogging, and soon the log condenser was substituted and was used until the introduction of the upright tubular one. These log condensers were made by attaching, by a copper tee, a large-sized copper pipe, called the log, to each of a pair of retorts. Near the ends of this pipe were copper connections, joining the large log to a

smaller one, and this in turn was similarly connected with others progressively decreasing in size. The whole log condenser lay in a plane at an angle of 45 deg. and the whole was surrounded by a wooden box with water inlet at bottom and outlet at the top. The joints were simply slip joints and were slipped together and "sweeled"; that is, wrapped with a cloth liberally covered with red lead, which after becoming dry or "set" offered a suitable and effective joint. At the ends of the logs were removable slip joint caps, for cleaning purposes, thus the cleaning from the heavy tarry and carbonaceous bodies was easily accomplished.

The first really important change in the general style of operation was that of replacing the old retort by the oven, which was done in the middle nineties, and is claimed to have been first tried out at Straight Creek, Pa. This change was wholly mechanical, and consisted merely of substituting for the retort a large rectangular oven, equipped with rails on the bottom for the purpose of carrying cars. These cars were loaded with wood and could be quickly pulled in and out mechanically and the charcoal unloaded outside the oven, greatly increasing the economy in this part of the operation over the slow hand drawing of the charcoal of the retort system.

There appears to be, however, much more advantage in this style of operation than the mechanical advantages which were at first anticipated, as an increased yield of products is obtained, due undoubtedly in part to more advantageous manipulation, but in our opinion also to the different chemical reactions that take place. In the old retort system complete carbonization of the wood took place in about sixteen hours, and it required in the oven system twenty-four hours, yet the temperature of the gases at the neck are higher in the latter, running at a maximum under skilful manipulation to about 330 to 360 deg. C., while in the former case the operation was consummated at not over 290 deg. maximum. This maximum temperature is obtained about midway or two-thirds of the run, at which time a very decided exothermic reaction takes place, and care must be exercised that the liquor is not "burned"; that is, that the temperature is not permitted to rise. If this happens, undue formation of condensation products results, which is immediately indicated by an increased flow of gas and a darkening of the crude liquor. This exothermic reaction, which also takes place in coal distillation, probably accounts for the increase in temperature of the uncondensed gases in the oven system, since no greater

proportionate radiation takes place in this system than in that of the retort construction. At this particular stage, on account of the nature of the source of the heat (exothermic changes in the wood) a much more uniform temperature throughout the oven is maintained. This gives an excellent illustration of the possibility of considerable alteration even in the chemistry involved in a process when we change the mechanical manipulation.

An additional advantage obtained by this oven system is that the charge of residual charcoal may be drawn while the oven is still hot, thus economizing on the fuel necessary for reheating, while a partial cooling is necessary in the hand-drawn retort system

The time lost during this cooling was saved in one design at Dahoga, Pa., where the retort at the conclusion of firing was removed by a crane from its vertical setting and replaced at once by a previously charged retort. It is stated in the meagre literature on this industry that "this type is probably most used."* This Dahoga installation, though it operated for many years, was the only plant that ever was installed in this country so far as we are aware, and certainly there is little likelihood of any existing now, for this one was recently converted into an oven plant.

There is still a third system, which should be at least mentioned, namely, the kiln system. This was really the second in date of development, but the oven system was so closely allied in design and operation to the original retort system that the two were taken up together. The fact is, we would expect the logical development to have been. Charcoal heap—charcoal pit—charcoal kiln—by-product charcoal kiln—retorts—ovens, but this does not appear to have been the case, in this country at least. As in the coke industry we do not appear to have gone from bee-hive oven to by-product bee-hive oven, directly, but through the by-product oven, an outside and distinct invention, so in this industry charcoal kilns were converted to the by-product kiln system only after the development of the retort system.

When charcoal was produced in kilns, from 20 to 86 cords of wood were placed in a kiln constructed of bricks, and wood was used as fuel for carbonizing. The volatile products were lost through the opening provided at the top. With the advent of markets for alcohol and acetate some charcoal manufacturers placed a pipe connecting this opening with a suction fan and a condenser

*Met. and Chem. Eng., 1910, p. 155.

and thus collected the volatile products. The amount of product thus recovered is but a fraction of that recovered in a retort or oven system. In Pierce's system the flat-topped circular kilns usually hold 50 cords. They are heated by gas burned in a furnace under the kiln. For the sake of brevity, a description of these interesting kiln plants will be omitted since their recovery of by-products is low and they are confined almost exclusively to the blast furnace plants of Michigan, where

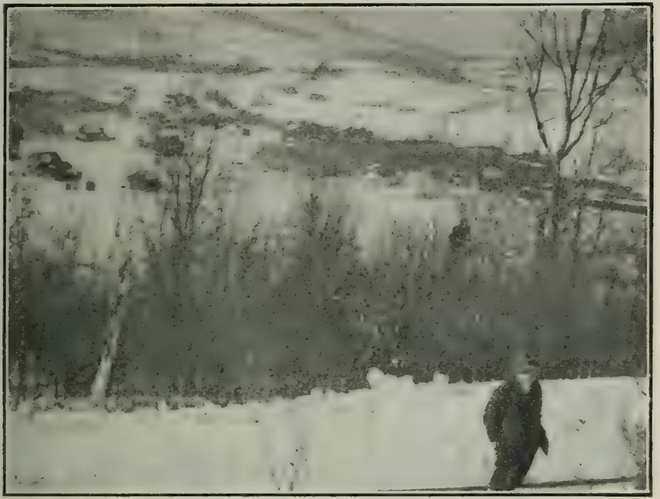

FIG. 4—A PENNSYLVANIA 66-CORD PLANT

they are steadily and rapidly being displaced by oven plants.

Yields

The low yield from the kiln system, which runs about 100 lb. of acetate of lime and 4 gal. of alcohol per cord, together with the low yields obtained by *rapid or quick* firing plainly show that there is a mean temperature which gives the maximum yield. Just what the curve of efficiency is, to our knowledge, has never been definitely determined in a commercial plant, though we have given it much experimental attention and others doubtless have worked on it also. In fact, there are so many factors to be considered in a comparison of experimental operations on a commercial scale that while the factors causing increased or lessened results are known, it is difficult to obtain accurate definite knowl-

edge as to just how much each factor contributes to the results. For example, we know that Michigan plants under approximately the same construction and operation obtain less product per cord than those of New York and Pennsylvania without certain knowledge of the relative influence of the various contributing factors.

This lack of definite data on a commercial scale, so deplorable in most industries, results from the difficulty of obtaining successive tests with all conditions alike, for we well know that any variation, for instance, of temperature, has a peculiar relation to the results obtained. In addition it goes without saying that the variety or species of the wood enters largely into the results obtained, and even the part of the tree used may cause variation. For example, a charge made up wholly of heart-wood will give better yields under the same conditions than a charge of slabs, making due allowance for the bark. Again we have found that weight for weight, cord-wood obtained from the mature or virgin trees will yield higher than the small second growth; also we are convinced of a noticeable difference in results from wood of the same species grown on high and dry places, and that from low or marshy soil, the latter giving a slightly lower yield. Indeed it is interesting to hear the experienced operator maintain that wood cut in the winter months will give better results than if cut while the sap is running. We are, however, unable to verify this expression, and it is possible that some other factor may have been responsible for this often-repeated statement. It is also held by many operators that eliminating the consideration of extra fuel necessary for the charring of green or unseasoned wood, the results are not the same in finished product as from well-seasoned wood. We can see from these statements that with so many factors to be considered, it is extremely difficult to determine which enter most into the discrepancies between the various systems; retort, oven, and kiln. However, from the purely practical standpoint we do know that there is a marked difference between yields obtained from the different systems as well as from the two general localities extensively operating.

If we compare the results obtained by the same system operated in the Allegheny Mountains with that of the Lake Superior region, we find that by taking the results on a yearly basis from a well-operated plant and calculating the wood on a basis of a cord 8 in. by 4 in.

by 52 in., there should be obtained conservatively 216 lb. of 80 per cent acetate of lime, 11.3 gal. of 82 per cent crude wood alcohol, and 52 bu. of charcoal. The yield from the Lake district is slightly under this in alcohol, and decidedly so in the acetate yield, which is 175 lb. to 180 lb. on continued operation. However, here again we have at least two factors and it is difficult to determine their relative influence. First, in the

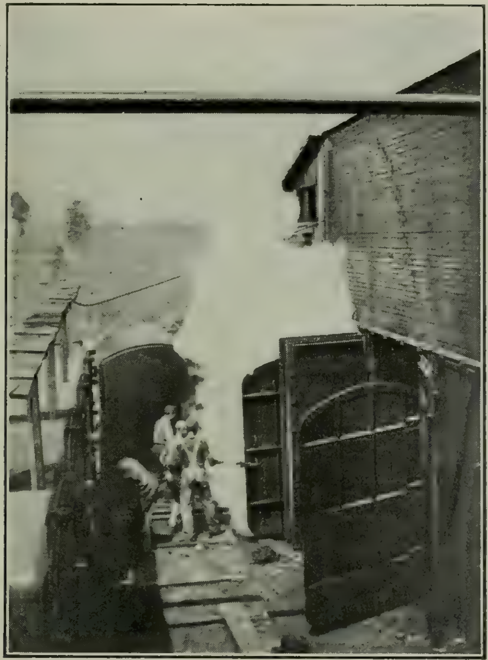

FIG. 5—START OF OVEN PULLING

Eastern field, beech predominates, while in the other hard maple is in larger proportion, and also slab wood is used much more largely. In fact, we have been unable to obtain data from a continued operation in which at least a small proportion of slabs was not used.

Construction

At this point it may be well to take up the question of construction, especially of the most successful and modern system, that of the oven, which is, with the exception of the mechanical manipulation, similar to the retort system.

The ovens are of uniform height and width, in most plants being 6 ft. 3 in. wide and 8 ft. 4 in. high, the length determining the capacity, running from 26 ft. to 54 ft. and holding from 5 to 10 cords. The steel used in the shell is usually 3/8 in., while the bottom and back heads are of 1/2-in. material. Ovens are built either with doors at both ends in order to withdraw the residual charcoal coincidentally with refilling the oven with wood-loaded cars, or in many cases, with a door at one end, the oven being loaded after the charcoal has been run into the coolers. In any event the door is hung upon a cast-iron frame riveted on the oven. This frame has a groove of about 1 in. for the use of asbestos packing and the cast-iron door is hung to the frame by riveted cast-iron hinges. The oven is stiffened by means of angle irons riveted perpendicularly on the sides, and on one side near the top are riveted 30-in. cast-iron nozzles, usually two in number, to which are attached the condensers.

The first ovens installed were placed upon piers in the setting, upon which were iron plates and rollers to accommodate expansion of the oven, but in the later settings the ovens are suspended from tee rails laid across the brick setting at the top and supporting the oven by means of U-bolts riveted thereto. The bottom of the oven is equipped with clips for holding the rails which carry the wood cars. These cars vary but slightly in length in different plants, running from 10 ft. 4 in. to 12 ft. 4 in. inside length and about 78 in. high, thus each car holds from 2 to 2 1/2 cords of 52-in. wood. Each has four 18-in. wheels with roller bearings running on 2-7/16-in. turned steel axles.

Immediately in front of the ovens are two charcoal coolers arranged in series and approximately of the size of the ovens. Into the first the hot charcoal is drawn from the retort, where it stands for twenty-four hours. From this cooler it is drawn into the second one for another twenty-four hours of additional cooling. These coolers are made of very light iron with cast door frames riveted on each end, and light sheet-iron doors. No bottoms are required as the coolers are simply placed on the ground and banked along the sides and doors with loose dirt.

To the nozzles heretofore mentioned are connected the condensers. These are upright tubular condensers, made with copper hoods having a removable head and are bolted to gun-metal heads which are bored for the copper tubes, usually 1 1/4-in O. D. seamless copper, and

expanded into these gun-metal heads, the whole surrounded by a steel water-jacket with water inlet at the bottom and outlet at the top. Connected to a bottom pan bolted on the lower head is a goose-neck trap for trapping off the non-condensible gases, thus separating them from the pyroligneous liquor, which is run into a wooden tank. The gas from the charge is carried into a main gas line which runs to the boilers where the gas is injected under them by a small steam jet. This jet performs the additional and very important function of serving to reduce any back pressure on the ovens, thereby preventing leaks. In order to prevent this suction from becoming too pronounced and drawing over the lighter volatile products through the condenser into the gas line, a butterfly or clapper valve is arranged on the line and regulated by a spring so set that any undue suction opens the valve, thus relieving the line.

Primary Distillation Operation

After this general outline of the first stage of the construction let us follow the operation to this point. After the loaded cars are run into the ovens the doors are pinned shut with taper pins driven into lugs which are a part of the casting of the door frame. The fires are started under the ovens and in about an hour the water distillation and first dissociation begins, the distillate being of a very light yellow color and having a tannin-like odor, and running about 2½ per cent of acid during the first hour when well-seasoned wood is used. Gradually this acid content rises until at about the fifteenth hour, when the content should be running from 12 to 14 per cent. After a few hours' running a small percentage of light tar begins to appear and steadily increases until at the latter end of the run tar is by far the larger constituent of the distillate. The acid content of the watery constituent gradually diminishes until it is almost negligible.

The product obtained under the usual practice, with average wood of at least a year's seasoning, is from 215 to 220 gal. of crude pyroligneous product giving an acid titration of 8 to 8½ per cent and an alcohol content of 4 to 4½ per cent. The tar yield is from 22 to 25 gal. to the cord, with a residual charcoal in the cars of about 52 bu. of 20 lb. each. With green or unseasoned wood the total distillate is diluted and will run from 275 to 325 gal. of liquid.

In the early stages of the run the non-condensible

gases are largely air and carbon dioxide. Therefore for the first few hours, and even after much of the hydrocarbons and carbon monoxide are accumulating in the gases they have no fuel value. However, the percentage of carbon dioxide diminishes rapidly, and from the middle to the end of the run the oven gas has an important fuel value. The total amount of gas will run from 11,000 to 12,000 ft. per cord.

As we have already intimated, the influence of the temperature of dissociation is extremely important, and the yields are much dependent upon its regulation. For

FIG. 6—CHARCOAL COOLERS. A NEW YORK PLANT

example, if during the height of the run the temperature at the neck of the oven materially exceeds 750 deg. Fahr. much greater volumes of non-condensible gases are being formed, together with an excessive amount of tar, and it is quite possible to lose from 5 to even 10 per cent of charcoal, together with a serious loss both of alcohol and acid content. Rapid firing, however, without reaching excessive limits will materially increase the acid content at the expense of the alcohol, while slow, even firing, operating the oven at a period in excess of the usual twenty-four hours, will increase somewhat the alcohol production and lessen that of the acid.

The interesting results obtained from excessive firing arise, as we hope to show later, both from a differ-

ence in the chemical dissociation and also from the subsequent formation of condensation products.

In drawing the hot charcoal from the ovens, quantities of combustible gas remaining in the ovens would cause explosion on the opening of the doors. This is obviated by the introduction of live steam into the front of the oven for a short time before the drawing is made.

Handling the Crude Distillate

The crude distillate or pyroligneous acid, called in the works "raw liquor," is first pumped into a series of wooden settling tubs, connected by brass piping. The first tub, where the greatest amount of tar settles, is connected near its top with an overflow pipe to the second tub. The second tub is connected with the third by a pipe somewhat lower, and this series of drops is continued so that the last tub is drawn from within about 18 in. from the bottom. The raw liquor thus settled free from tar is, as a rule, continuously run into the copper stills. These copper stills are for the purpose of distilling off the lighter volatile products away from the tars and oils which remained in solution in the settled liquor. They are from 7 to 10 ft. in diameter with proportionate height, made of 12 to 14-gage cold-rolled copper, and equipped with a steam coil, usually of 3-in. or 4-in. seamless drawn copper tubing and starting from about 18 in. from the top and running helically around the walls and on the bottom to midway between the center and periphery. For a 2000-gal. still from 300 sq. ft. to 400 sq. ft. of heating surface should be used. In addition each still should be supplied with a live-steam jet applied at the bottom and preferably through a copper ring having small steam openings.

After a copper still has run continuously for some time it gradually becomes filled with deposited tar and its flow of distillate diminishes. When this has reached a stage of very slow production, as it does every four days, the feed valve is closed and the live steam jet is opened, distilling the tar with live steam, thus obtaining considerable quantities of acid and light oils. This latter distillate is run into separate tubs, where the light oil on the top is withdrawn before the acid liquor is pumped into the original copper still distillate which has been run into a wooden "mixing tub." The tar from the settling tubs is usually distilled in a separate tar still, sometimes made of wood, and dis-

tilled as has been that just described. This practice is followed as it permits the separation of the oils independently and without allowing them to come in contact with the original distillate, in which a portion would dissolve, thus the bulk of the distillate contains less impurities by this practice.

The mixing tub is usually from 12 to 14 ft. in diameter, and 4 ft. high, having a very heavy wooden stirring arm fastened to the end of a heavy shaft, operated by a slow moving gear at the top. Slaked lime is slowly added to the liquor in the tub, which contains its own indicator, the liquid changing at the neutral point to a pronounced wine color. For maximum yields, however, probably owing to the acetic esters present, the addition of lime should be continued until this color has been followed by a yellowish one and until a bead appears or bubbles form on the surface and which disappear slowly. A very small further addition of lime at this point causes the acetate to stick to the pans when evaporated and prevents satisfactory crystallization. Under-neutralization also causes inferior quality in crystallization, and before final drying the acetate has a decidedly black color instead of a rich yellow brown, and there is an accompanying loss in product owing to the esters lost.

From the mixing tub the neutralized liquor is jetted or run into an iron still known in practice as the "lime lee" still. In a few plants this is equipped with either Burcey pans, or in some more modern works with a fractionating column, although most plants do not fractionate at this point. The customary practice is simply ordinary distillation. The crude alcohol starts over at about 20 per cent on a Tralle scale, but quickly rises to 35 per cent and at times 40 per cent, gradually dropping in percentage to from 15 to 20, at which strength it continues for some time and then drops rapidly to 5 per cent or 6 per cent, at which point it seems to hold stationary again for a long period. After all of the alcohol has been distilled over, a valve in the vapor neck is closed and the residual acetate solution is blown, by means of live steam pressure applied in the still, to an iron settling pan above the top of the ovens, where the excess lime and insoluble impurities settle out in a few hours. The acetate liquor is then drawn into flat steam pans having a jacketed bottom for steam supply, the pans usually being about 16 ft. long by 8 ft. wide and 18 in. deep. Here the acetate liquor is boiled rapidly until crystals appear on the

surface near the edges, when the steam is reduced so that the crystalline film which forms at once on the top does not break, which would cause it to fall to the bottom and form a hard crust. Care must be exercised in this "seeding" process, as it is called, or a great quantity of this exceedingly hard crust or scale will be produced, which is unfit for the market. After this "seeding down" has continued until the whole mass in the pan has reached a very thick mushy consistency, it is shoveled out on the acetate or "kiln floor," which is a smooth brick or tile covered floor over the top of

FIG. 7—DUMPING CHARCOAL

the ovens. Here the acetate is continually turned until dried and ready for sacking and shipment.

The "weak alcohol" from the "lime lee" still, containing from 9 to 12 per cent of acetone and alcohol, is accumulated and distilled in an iron still having either 5 or 6 Burcey pans or a column. This distillate is the final crude product produced by the works, and is usually shipped to a central refinery, although a few plants refine their own product. In this distillation all the product coming over above 60 per cent is run into the storage tank, and the lower fraction is put back with the lime lee distillate for further distillation. The finished crude is sold on a basis of 82 per cent and contains about 16 per cent acetone.

Returning to the copper still residue, the tar from

these stills, as well as that from the tar still, is run into a sump and from there jetted under the boilers for fuel. The two fuel products, gas and tar, furnish approximately 35 per cent or 40 per cent of the necessary fuel for all operations.

Before leaving this subject of operation it might be said that many of the earlier plants omitted this copper still distillation, neutralizing the raw liquor directly after settling and thereby obtaining the "brown acetate" of commerce, which is to-day practically without market. This brown acetate runs from 60 per cent to 65 per cent acetate.

Production Costs

The costs of producing the products above mentioned have been on a constantly increasing scale, owing in a large measure to the increasing cost of cord-wood and stumpage. During the past fifteen years in the eastern district, stumpage in suitable location has been sold for as low as 15 cents per cord, while to-day 75 cents to $1 is the approximate average. The cost of cutting varies from $1.15 to $1.35 per cord in fair timber, and in scattered timber $1.50 is sometimes paid. To-day, including transportation, piling, etc., this will make the cost on board oven cars $4 to $5 per cord, though wood is being put in for as low as $3.50 by users of mill-waste or by those having long standing holdings.

This gradual rise in the cost of wood is due to natural causes, among which are the increase in stumpage cost due to the ever-decreasing supply, and the natural rise in labor, together with increased length and cost of transportation. With the exception of one possibility, there appears to be no hope of any future lowering of costs. This one exception, a new cord-wood splitting machine, appears from our examination to have merit, and presents an entirely new system of cord-wood production. It is generally conceded that cutting and hauling the large log is less expensive than cutting and handling the cord-wood at the stump. The tree is therefore cut in logs and large limbs and transported to the machine, where a slide carries it first to a cross-cut saw, which cuts it into the proper lengths. The sawed pieces continue to a platform where they are either split in halves or quartered by one blow. The split wood automatically moves by a slide to the railroad car or wagon. It is claimed that under suitable conditions 50 cents per cord, or in some instances even more, may be thus saved. We have been unable to see

continued operations of this machine as yet, and consequently cannot verify this saving cost, but are inclined to believe that at least some reduction in wood cost is possible by this means.

The cost of fuel for a crude works, in addition to the tar and gas used, of course varies with the available supply. In the New York and Pennsylvania districts, when coal is used, this cost will amount on an average to $1.15 per cord, and when natural gas at 15 cents per thousand feet is used the cost is but slightly more. The labor at the plant is usually counted at $1.25 per cord.

TABLE I—PRODUCTION COSTS PER CORD OF WOOD

Wood (maximum) per cord		$5.00
Fuel		1.15
Labor		1.25
Lime, 0.96 bu. at 19 cents		.18
Bags (acetate)		.14
Freight (acetate, 16 cents per 100)		.35
Freight (alcohol)		.10
Selling commission acetate		.11
Insurance, per cord	.068	
Taxes, per cord	.112	.57
General expense		
Total		$8.85

The summation of production costs given in Table I (above) will be generally accepted as a fair basis in considering investment in new installations.

Production Values

With the present slump in markets the values herein set down are low, especially that for acetate of lime. The past 10-year-average would be about $2 per hundred, while at present the market is slow at $1.75 per hundred.

Alcohol (82 per cent), 11. gal. at 25 cents	$2.75
Acetate of lime, 216 lb. at $1.75	3.78
Charcoal, 52 bu. net at 6¼ cents	3.38
Total crude value	$9.91

This gives a production cost of $8.85 and a sales value of $9.91 per cord. It will be noted that no selling costs except in the case of acetate of lime have been included, because in the works not refining or

making the finished products, which are in number far in excess of those who do refine, the alcohol is sold under contract to the refiner, and the charcoal is either, as in the case of those plants in the Lake district, consumer at iron furnaces in connection with the plants, or as in the eastern field handled by a general sales agency controlled by the manufacturers, proportionately to their daily production capacity, yielding to the producer about the above mentioned figure at present.

These production costs are based on the yields in the eastern field, which, as pointed out, were higher than those of the Lake region. This discrepancy is compensated however by the fuel and wood costs being lower in the Lake region, owing to the fact that in most instances mill-waste is used. The general relation between the two fields of operation in this production cost and product value is therefore approximately the same. It is undoubtedly true that many manufacturers can show much greater net profit than the above figures indicate, because of cheaper wood and fuel, and in some instances because of plant design.

Costs of Installation

Eliminating the cost of wood supply, $2,000 per cord per day production is counted as a reasonable installation cost for a plant as described, for producing crude products. For instance, the cost of boilers, ovens, cars, coolers, pumps, etc., is substantially $650. Copper work, including stills, condensers, piping, etc., approximates $450. Brick work for ovens and boiler setting, etc., will come to about $190. These three general items are more or less about a fixed estimate, varying, of course, somewhat upon the price of materials at the time. The location, buildings and general costs vary with the design and the desire of the builder. However, the above stated general figure of $2,000 is a fairly accurate estimate, unless elaborate construction is undertaken.

Large Scale Experimentation

Realizing the possibilities and necessity of counterbalancing the increasing cost of production, several large operators have made extensive large scale experiments with a view to increasing yields and saving production costs. Unfortunately the results obtained thus far have not justified the expenditures made in spite of many optimistic claims (Met. and Chem. Eng., 1910, p. 434), owing in a measure to the many unlooked for

complications which arise between the laboratory and the works scale. Of the great amount of work which has been done along this line with which we happen to be familiar, space permits the citation of but a few illustrative instances.

In the fall of 1908 certain men largely interested in the business went to Germany to investigate developments there and returned with a process for eliminating the copper stills and making gray acetate of lime directly from raw liquor, a proposal which had already been made and studied in this country. This process

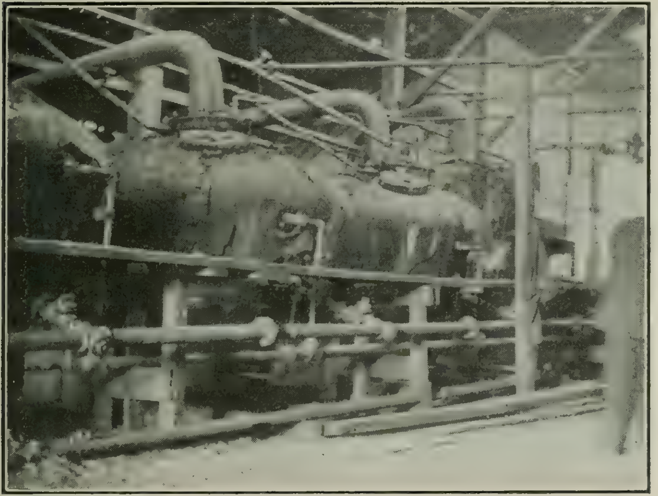

FIG. 8—ANCIENT TYPE OF COPPER STILLS, FORMERLY DIRECT FIRED, THEN CONVERTED TO STEAM HEATED IN A NOW DISMANTLED RETORT PLANT

had been reputed to be in successful operation in Germany. It was in fact merely the application of the cup column to the neck of the ovens. The cups and openings were of course of larger size than in the customary column, but in effect this really was all that could be claimed for the new appliance. It was held that the pyroligneous vapors, passing through the condensed tarry liquor, were freed from their impurities by this means and that gray acetate could be produced from the resulting raw liquor by direct neutralization. Educated or impressed by the then incomplete American investigations mentioned, these men permitted themselves to

be carried away by the assurances of the German engineers and, as has happened several times in our industrial chemical development in more or less identical circumstances, without adequate experimental investigation they equipped a large plant with this apparatus at an enormous expense, the copper work for which alone exceeded $80,000. The plant did not prove satisfactory.

It will at once be seen from foregoing statements in this article, that there were two fundamental reasons which explain, in our opinion, the failure to obtain the desired results. First, as pointed out, mechanical clogging of the apparatus would occur, as was the case in the original worm condenser; and second, as we believe, the valuable products readily form condensation products with the unsaturated hydrocarbons and aldehydes present in the distillate. Certainly the passing of these vapors through the hot tarry liquid would tend to increase this chemical reaction. Moreover, the apparatus caused back pressure on the ovens and required a suction to overcome this objection. This increase of suction would tend to bring the vapors through the cups and the condensers at a more rapid rate, which of course would lessen their efficiency.

Later another process, also brought from Germany, was tried, which was in effect the same as the one above described, except that the vapors were forced through a body of hot tar for the purpose of washing them, but this also was not successful. In our opinion this was for the same fundamental chemical reason as mentioned above.

A process for accomplishing this result, but not as yet entirely developed, from which some very satisfactory results have been obtained, is based upon a totally different theory from those mentioned. This method places a fractional condenser on the neck of the oven, which is maintained at a temperature sufficient to liquify the high boiling tars and oils. These, however, are largely mechanically carried along by the uncondensed and non-condensible gases, while a part of the tar is run off through a goose neck on the bottom of the fractional condenser, the uncondensed vapors and the non-condensible gases with their suspended tar and oil liquids are carried into the bottom of a centrifugal basket or drum, installed in a copper container and having small perforations inside of the drum, which is supplied with wings to give a rapid motion to the gases. This centrifugal action throws the liquid

particles or mist against the side of the container, on which are deflectors set at an angle opposite to the direction of the moving drum. Thus the condensed bodies are forced to the bottom of the container and out of the zone of circulation, through a goose neck into the tar receiver, while the vapors continue to a second condenser and are there condensed, the wood gas being trapped off in the usual manner.

This process has given uniformly increased yields of product, but exact data as to saving, yields and cost of operation have not been determined as yet. A little over one horsepower is necessary for the opera-

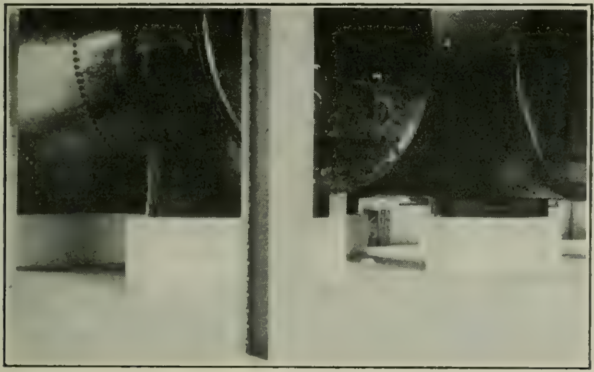

FIG. 9—SODA STILLS. WOOD ALCOHOL REFINERY

tion of a 7-cord machine until speed is attained, then three-fourths hp. is necessary.

The increase in product yield with this method is probably due to the fact that the vapor contact with the condensed and unsaturated bodies present is reduced to a minimum.

Another attempt at fuel conservation, which it seems should be possible of accomplishment, relates to the evaporation of the acetate liquor. As has been seen, much heat is necessary for evaporation of this liquor, and this method attempts to utilize the high temperatures of the gases at the oven's neck before they enter the condensers. We are not aware of any installation of this nature, although patents have been issued for accomplishing this end. Nevertheless, as it involves what appears to be a wholly mechanical manipulation there should be no great difficulty in saving at least a portion of this waste heat. Here again it can be seen

that experimentation to accomplish this end is costly, since all experimental changes necessitate considerable financial outlay if tried on a large oven, and also involve interruption of regular operation which must from time to time inevitably occur.

Under this head of experimentation may properly come an elaborate attempt to utilize hardwood sawdust for alcohol manufacture. This was undertaken in 1903 by a well known lumber company in Cincinnati, who endeavored to destructively distill sawdust continuously by means of an endless belt which carried the sawdust through an oven for the purpose of carbonizing, tapping off the pyroligneous vapors, and obtaining an uninterrupted production of charcoal, which was briquetted. The distillate was handled in the usual manner.

It can be readily seen that sawdust can not be destructively distilled in bulk, as is cordwood, for the insulating space between the particles prevents the heat from going through the mass. This explains the reason for the endless belt.

No expense was spared either in buildings or equipment, the buildings being of stone and the equipment of the best; the whole costing probably $200,000. Notwithstanding this outlay the operation was a complete failure, the plant being dismantled within a year and the buildings used for other manufacture. The high fuel cost in attempting to overcome the resistance to radiation in such a mass was an important item in the high production cost which resulted in the failure. In addition, sawdust charcoal is a more dangerous fire risk than common charcoal, in the handling of which in the ordinary plant special arrangements are necessary.

Within the past five years some plants have installed double and triple effect evaporators with a view of fuel economy and reports as to the results are very contradictory, but the continued use indicates at least partial success. One Michigan plant is successfully drying its acetate with a drum and belt dryer. Vacuum drying for acetate has been tried, but we are unaware of any success, as the resultant product is a powder while the market demands the crystal.

Refining

From the time of the formation of the already mentioned Burcey Refining Company, the usual plan of manufacture contemplated only the production of the crude product as described, selling the product, those of

the Eastern field, largely to a Buffalo refinery, and the Michigan manufacturers to Detroit, and up until the passage of the Denatured Alcohol bill by Congress they received a price usually ranging from 40 to 75 cents a gallon for the crude alcohol. After the passage of this act, and with the purchase of the Detroit plant by the one at Buffalo, the price of crude was at times as low as 15 cents per gallon, and during this period of adjustment intense depression prevailed amongst the crude producers, as it was feared that ethyl alcohol would largely supplant methyl. It was found, however, that the trade, particularly the paint trade, preferred wood alcohol even at a slightly higher price, and this fact virtually saved the industry. With the formation of a refining company among eastern crude operators representing somewhat over 1000 cords daily production, and the erection of a refinery at Olean, N. Y., the monopolistic control of refining was immediately reduced. A very acceptable dead rental was paid to the crude producers for their uncompleted refinery, as well as a substantial increase for their crude product, which eventually reached and is maintained at about 25 cents per gallon of 82 per cent product.

The method first employed by refiners was merely that of fractional distillation, and we all perhaps will remember the yellow, ill-smelling wood alcohol of commerce. Later, and for a long time, bleaching powder and sulphuric acid were used before the final distillation. This materially improved the product, but with the improvement of the columns used, treatment with sodium hydroxide and distillation is all that is necessary. The NaOH serves the purpose of polymerizing the aldehyde impurities and saponifying the tarry matter. The esters present are also affected. The formerly objectionable acetone present, which distills with the heads, now has its own market value under the name of acetone-alcohol and is used in varnish removers, as a solvent in the rubber and other industries and also as a carrier for acetylene gas in lighting systems. Thus this 16 to 18 per cent of impurity is now in fact an added value to the refiner.

Markets

Prior to the present unfortunate European situation the average production of acetate of lime from the manufacturers in this country amounted approximately to 7000 tons monthly, and we are informed that the total European and Canadian production is almost equal

to this, of which tonnage Austria-Hungary furnished about two-thirds. The plants in Europe, however, are usually on a very small scale in comparison with those in this country. Sweden alone has plants of a size in anyway comparable with the larger ones here. Of the production of acetate in this country, from 50 to 60 per cent is exported, a considerable percentage to or through Belgium. Of course, it will be understood that these statements refer to the market situation before it became demoralized by the European war, although for a year prior to the declaration of war there had

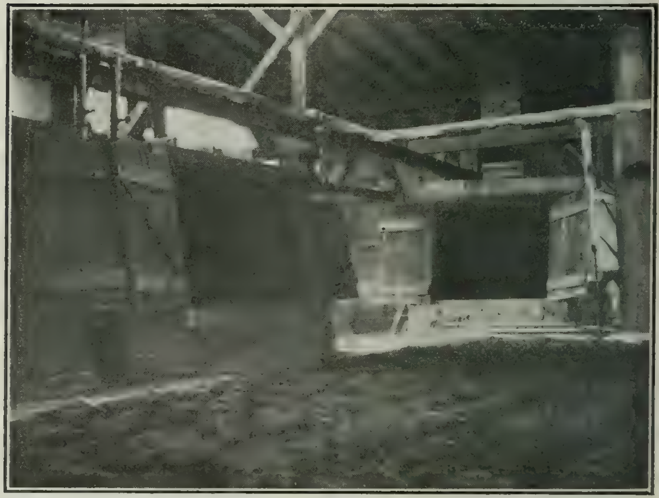

FIG. 10—ACETATE PANS AND KILN FLOOR

been a pronounced stagnation of the markets both at home and abroad.

Of the acetate of lime consumed in this country, by far the largest percentage goes into acetic acid production. The hardwood industry is therefore vitally connected with this acetic acid industry, and one of the most important developments in the last decade is the successful beginning made in combining the crude manufacture and this refined or finished product manufactured in the same plant. Such combination plants have shown crude acetic acid yields in continuous operations running 92 to 96 per cent of theory, using 5 per cent sulphuric acid in excess of that theoretically required, and giving on a continued daily production of

4000 pounds, with a yield of 91 per cent of the possible theoretical yield, refined acetic acid of the finest double distilled quality.

The chief individual acetic acid market demands in this country are from the manufacture of white lead, paint colors and the textile and leather industries, although in the aggregate the small consumers such as the laundries, ink and drug trades, consume great quantities. This country prohibits the manufacture of acetic acid vinegar, but its production is permitted abroad.

The consumption of export acetone produced in this country is chiefly by England, and Italy is just now a large consumer. The industry is in a particularly thriving condition at the present time owing to its use in production of explosives for the European war. There should be obtained 20 to 22 pounds of acetone per 100 pounds of acetate used, and in connection with the crude works acetone production is very profitable, as the general operating expenses are low. Of course its use in this country was very large for explosive manufacture and for the production of chloroform under the well known Rumpf patents, regarding which there was so much patent litigation some years ago and which as you know were upheld. In comparatively late years, however, a large Michigan concern has produced chloroform commercially from carbon tetrachlorid, which has probably influenced somewhat the acetate consumption for this manufacture. There are four plants in the United States producing acetone for the market and within the past week ground has been broken in Pennsylvania for a fifth plant. There is but one plant operating in Canada, to our knowledge.

Ten years ago the steel industry consumed by far the major percentage of charcoal produced. This percentage, however, has decreased considerably owing to the improved methods for steel production. Many industries such as cutlery and car wheel manufacture demand charcoal iron, but in these and many other instances coke iron has been substituted. This falling off in the proportionate use of charcoal in iron production has been made up in an increased domestic demand. Charcoal is now sold in small paper sacks in many cities for use both in hotels and private families.

The production of crude wood alcohol amounts to between 10 and 11 million gallons per year, and of course it has innumerable uses, including that of the paint industry, which is the largest single user.

Space will not permit in a general article such as this,

of going into details regarding production and markets of the other products such as formaldehyde, creosote, etc., which are directly or indirectly derived from hard wood distillation.

Distribution of Plants

Although not in agreement with any published figures, we place the distribution of distillation plants as follows:

Michigan	8	oven plants carbonizing	1032 cords daily
	5	kiln plants carbonizing	1050 cords daily or
	13	plants carbonizing	2082 cords daily
Pennsylvania	33	oven plants carbonizing	1424 cords daily
	13	retort plants carbonizing	215 cords daily or
	46	plants carbonizing	1639 cords daily
New York	7	oven plants carbonizing	256 cords daily
	17	retort plants carbonizing	362 cords daily or
	24	plants carbonizing	618 cords daily
Wisconsin	2	oven plants carbonizing	96 cords daily
	1	oven-kiln plant carbonizing	250 cords daily or
	3	plants carbonizing	346 cords daily
Kentucky	1	oven plant carbonizing	20 cords daily
West Virginia	1	oven plant carbonizing	49 cords daily
Tennessee*	1	oven plant carbonizing	32 cords daily
Vermont	1	retort plant carbonizing	16 cords daily

This makes a daily capacity in this country of 2909 cords in 53 oven plants; 593 cords in 31 retort plants and 1300 cords in 6 kiln plants or a total of 4802 cords in 90 plants.

In Canada there are 9 oven plants charring 424 cords daily and one retort plant charring 48 cords, or a total of 472 cords in 10 plants. This makes a total for America of 5274 cords per day in 100 plants.

These figures will mean more to us if we remember that 5000 cords of wood represent a pile 4 ft. high and 52 in. wide and 7.5 miles long, weighing when seasoned approximately 10,000 tons.

These figures show the importance and size of the industry in this country.

Conclusion

It will be evident that the chief economic drawback in the present manufacture is the fact that most of the plants do not manufacture the finished products, thus in general it may be inferred that two sets of freight charges, commissions and handling expenses are required before the products reach the consumer. For instance, with acetate of lime at $2 the net return to the producer is about $1.75 per hundred.

*A recently constructed 16-cord retort plant now being converted into an oven plant.

A large part of this difference could easily be saved by undertaking the manufacture of the finished product at the crude plants.

Hitherto such combinations of crude and finished product manufacture have been thwarted in the majority of cases by an almost complete monopoly of the finished products by certain groups of chemical manufacturers, who by various manipulations maintained control of markets, or who were able to dominate the

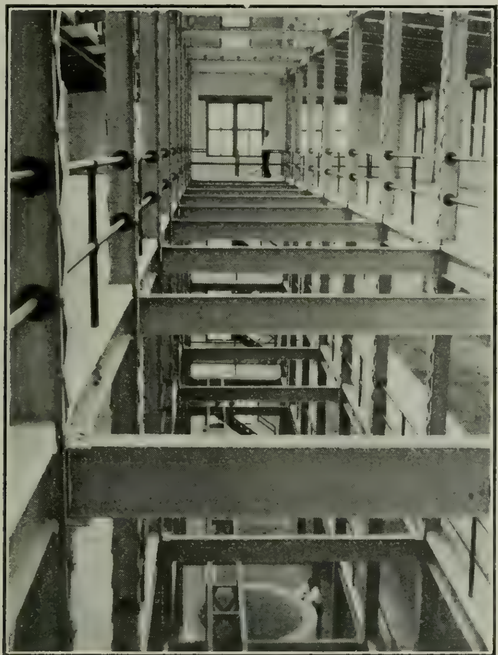

FIG. 11—THE COLUMN WELL IN WOOD ALCOHOL REFINERY

situation, as in the case of acetic acid, by their regional control of sulphuric acid manufacture, or even attempted control of pyrites importation. The violent market fights which have developed because of these facts have been carried through successfully in more than one instance by the crude manufacturer, because of his advantageous situation, and it is certain that these attempts, therefore, to thwart the natural economic development of this industry will sooner or later collapse to a great extent, or the refiner will be compelled to either go into the crude business himself or combine with the crude manufacturer.

We have attempted to show the difficulties met and the expensive experimentation that has been undertaken in the past for the improvement of this industry, and have pointed out some of the results thus obtained.

When it is remembered that German statistics claim that but one of fifteen serious trials of new chemical processes are successful and that this percentage amply pays for the losses entailed in the fourteen unsuccessful ones, it can be seen that while these expenditures are individually unfortunate, in the aggregate this law of averages will probably hold good in the development of this industry for its économic position demands the solution of the problems indicated.

Columbus, Ohio.

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LAPS AND LAPPING

BY

WILLIAM A. KNIGHT

AND

A. A. CASE

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LAPS AND LAPPING

By W. A. Knight and A. A. Case

ABSTRACT OF PAPER

This paper gives details of tests of abrasives when used for lapping operations with the object of determining the effect on the rate of cutting with different combinations of abrasive, lubricant, and lap material. The tests were made with hardened steel specimens, on a machine built especially for the purpose.

Comparative results were obtained with emery, alundum, and carborundum used in connection with lard oil, machine oil, gasoline, kerosene, turpentine, alcohol, and soda water. The lap materials were cast iron, soft steel, and copper.

The investigation shows that in general there is a lubricant that will give best results with a given combination of abrasive and lap. Thus, emery on the cast lap gives best results with gasoline and kerosene, while lard oil and machine oil are distinctly inferior. On the other hand, with carborundum on the steel and copper laps, lard oil and machine oil do the best work of any of the lubricants tested, while gasoline and kerosene do the least efficient work with these combinations. Lard oil invariably gives a higher rate of cutting than machine oil.

Carborundum usually gives a higher rate of cutting than the other abrasives but it also wears the lap faster. The tests show that carborundum wears the lap surface about twice as fast in proportion to the amount ground from the steel specimen as does emery, and the wear with alundum is one and one-fourth times that with emery. Also, the wear of the copper lap is about three times, and the steel one and one-fourth times, that of the cast iron. This wear is shown to be inversely proportional to the hardness of the lapping plates, as shown by the Brinell test.

Comparisons were made, too, between the ''wet'' and the ''dry'' methods of lapping. In dry lapping much depends on the manner of charging the lap. Results show that with the wet method the rate of cutting is two to six times as fast as with the dry, depending on how the lap was charged.

LAPS AND LAPPING

AN INVESTIGATION OF THE CUTTING PROPERTIES OF ABRASIVES WHEN USED WITH DIFFERENT LAPS AND DIFFERENT LUBRICANTS

By W. A. Knight, Columbus, O.

Member of the Society

and

A. A. Case, Columbus, O.

Non-Member[1]

The use of a loose-grained abrasive in connection with a lubricant, for working down surfaces, dates back to very ancient times. The method was first used in the grinding and polishing of precious stones. The workmen were called lapidaries and their tools, charged with the abrasive, called laps.

2 Later the process was applied to the working of hardened steel and, from this, gradually extended to cover a wide variety of operations common to machine-shop practice.

3 Several years ago, having occasion to seek definite information on the subject, it became evident that there were few, if any, exact data available. This led to the construction of a machine with which quantitative results could be obtained with various combinations of abrasive lubricant, and lap material. Tests on the machine were confined to surface lapping.

4 There are two methods of using a surface lap which, for want of better definitions, will be termed the "wet" and the "dry" methods. In the wet method there is a surplus of oil and abrasive on the surface of the lap. As the specimen being lapped is moved over it there is more or less movement or shifting of the abrasive particles. The action may be conceived to be somewhat as follows:

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For presentation at the Spring Meeting, June 1915, of The American Society of Mechanical Engineers, 29 West 39th Street, New York. All papers are subject to revision.

A particle becomes embedded in the softer surface of the lap, it remains stationary for awhile, but is finally dislodged by friction or change in direction of the rubbing surface. It then rolls around for awhile, only to lodge again and have the process repeated. Meanwhile the grains of abrasive are being broken up into smaller sizes, their sharp edges and corners worn away, the cutting effect grows less, until it becomes necessary to recharge the lap with fresh material.

5 With the dry method, the lap is first charged by rubbing or rolling the abrasive into its surface. All surplus oil and abrasive is then washed off, leaving a clean surface, but one that has embedded uniformly over it, small particles of the abrasive. It is then like the surface of a very fine file or oil stone and will cut away hardened steel that is rubbed over it.

6 While this has been termed the dry method, in practice the lap surface is kept moistened with kerosene or gasoline. This is for the purpose of preventing small spots of steel, called "birds eyes," building up on the lap surface. But there is not enough lubricant applied to "float" the piece being lapped and, hence, has been called the dry method.

7 Among mechanics there is some difference of opinion as to whether the cutting is more rapid with the wet or the dry method. By advocates of the dry method it is pointed out that in this the abrasive is permanently embedded in the lap surface, there is actual contact between the abrasive and the steel specimen, there is no floating on an oil film, no rolling on loose particles, that the cutting action is more nearly true, and hence more rapid than when these conditions fail to obtain.

8 Materials used for laps may be cast iron, copper, steel, tin, lead, or any combination of the softer metals to give varying degrees of hardness. The choice depends on first cost, permanence of form, rapidity of cutting, and ease of redressing.

9 The lubricants most commonly used are lard and machine oils, kerosene, and gasoline. Alcohol and turpentine have been recommended. It is well known that turpentine can be used to advantage when drilling hard steel. It causes the drill to "take hold" of the steel better. Whether it has a similar effect when hardened steel is cut by an abrasive is a question.

10 Abrasive materials are usually emery, alundum, corundum, carborundum, or others of a similar kind, but sold under

various trade names, as Crystolon, Axolite, Carbondite, etc. Diamond dust is also used and ground glass, oil stone powder, and ground pumice stone find limited application for certain kinds of work.

OBJECT OF TESTS

11 In the selection of the abrasive, both as to kind and size of grain, the metal of which the lap is made, the lubricant and pressure to be used, there is wide range of possible combinations for this work. The object of the experiments was to secure, if possible, reliable data on the following points:

a The relative efficiencies of the different abrasives.

b The relative efficiencies of different lubricants.

c The rate of cutting with laps made of cast iron, soft steel, and copper.

d The wear of the laps, compared one with the other and with the amount of steel ground off with each.

e The effect of pressure on the rate of cutting.

f The rate of cutting by the wet and the dry methods.

12 The problem was more difficult than appeared at first, and it was only after three months of experimental work, after having completed the machine, that the results obtained were considered of sufficient accuracy to warrant going ahead with the work.

13 The usual method was followed of keeping all variables constant except one, and having determined the effect of that one, to proceed to the next. It developed, however, that some of the variables affecting the results were not entirely within control. Thus, for instance, the size of the grains of abrasives is one of the factors affecting the rate of cutting. By the nature of the process the size of the grains is continually changing, being ground down to smaller sizes. This change in size depends on the pressure and to some extent on the lubricant and the material of the lap surface. Hence, the rate of change is of itself a variable.

14 Again, when using volatile liquids, like gasoline, turpentine, and alcohol, fresh additions had to be made to the plate to make up the loss from evaporation. At first the liquid was supplied to the plate through the medium of sight feed oil cups. This was impracticable, because at different stages of a test run, which required about an hour and fifteen minutes to complete, the liquid was required at a different rate. Also a different rate was required for

different pressures and it was impossible so to regulate the feed as to keep a constant degree of saturation on the lapping plate. It was found more satisfactory to supply the lubricant by hand from an ordinary oil can, watching closely and adding the lubricant as needed. This, of course, introduced a personal factor.

15 Another disturbing element was the pressure of the atmosphere on the test specimen. It is not believed that this was in any way serious, but there were occasions when the rate of cutting appeared erratic and variations in pressure seemed to offer the only reasonable explanation. Any one who has rubbed two smooth surfaces together, with a liquid between them, will have experienced the effect of atmospheric pressure. At times the surfaces will seem forced together more strongly than at others. This occurs when the air is wholly or partially excluded from between them. Further, this action is irregular, which means that it is impossible to maintain absolutely uniform pressure between the surfaces. The effect is more marked with large surfaces. During the experimental work, test specimens of 1-in. diameter were tried, but the results with these were not so uniform and consistent as with smaller sizes. The size finally adopted was $\frac{5}{8}$-in. diameter, giving an area of 0.306 sq. in.

16 The latter seemed to have a considerable influence on the rate of cutting. After a run with a pressure of 5 lb. per sq. in. on the specimen, irrespective of which lubricant was used, the plate would show a natural color and possess a uniform velvety surface. With the higher pressures, however, the plate often took on a more or less glazed appearance. In fact, it seemed as if the abrasive worked into the surface during a run with low pressure, would be smoothed down and form a kind of scale or false surface when the higher pressures were used. This was more in evidence with some lubricants than with others. To illustrate more clearly, the copper plate after a run with lard oil would be of a bright copper color, showing no evidence of discoloration. With kerosene, when the higher pressures were used, the plate became darker in color, showing that some of the abrasive had been worked into its surface. The plate also had a more glazed appearance. This, of course, changed somewhat the nature of the surface, but was unavoidable.

17 These things are mentioned to show more clearly the nature of the problem and to account for small variations in the results. Thorough precaution was taken to reduce all uncertain factors to

the lowest possible limit and confidence is felt that the results are well within the limits of practical accuracy.

DESCRIPTION OF TESTING MACHINE

18 The machine which was designed and used for these tests is shown in Figs. 1 and 2. The horizontal shaft *B*, driven by motor

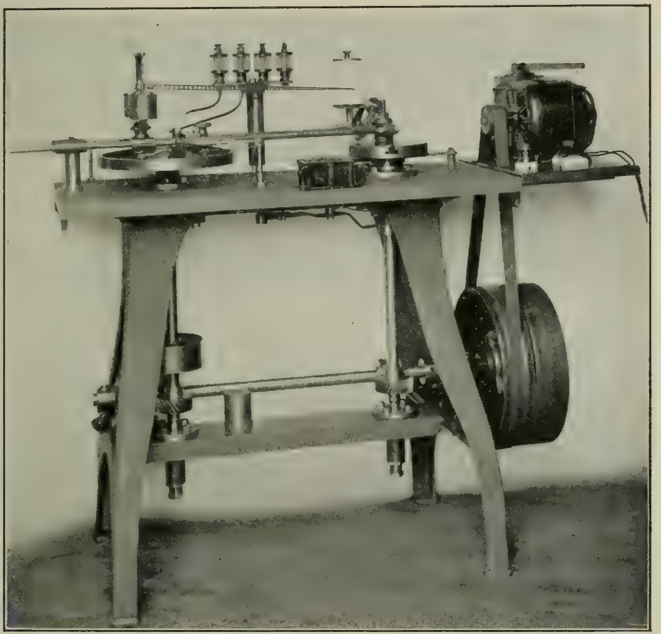


FIG. 1 MACHINE DESIGNED FOR TESTS

A, transmits motion through spiral gears to two vertical shafts *C* and *D*. Shaft *C* carries the lapping plate at its upper end and shaft *D* the slotted crank disk *E,* by means of which, and the connecting rod *F,* the specimen holder H is made to reciprocate between the center and outer edge of the lapping plate. The motions of the lapping plate and specimen holder cause the latter and its specimen to follow a path relative to the plate like that shown in Fig 3, which is from a figure actually drawn on the machine. Originally the plate made about 3 revolutions to 1 of the crank disk, but this was changed to about 1.8 to 1, which gave better results.

19 As at first constructed the machine was autographic, but

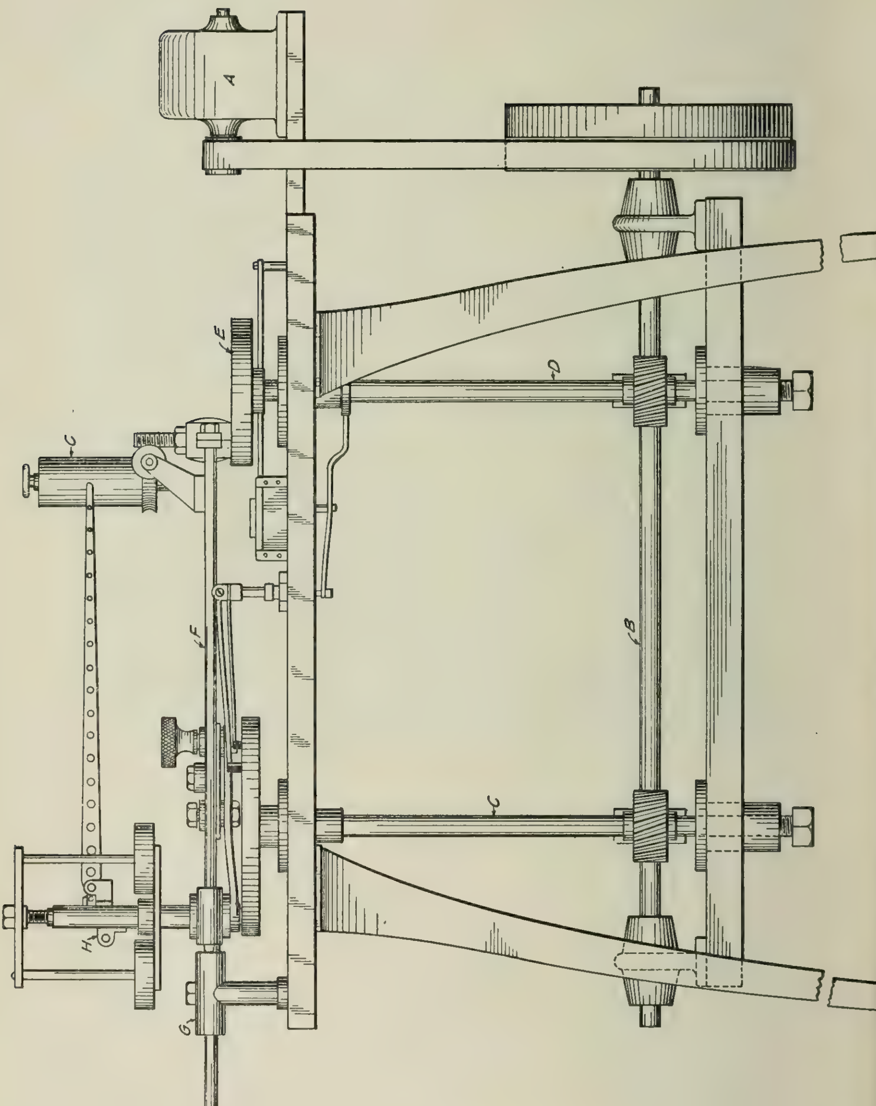


Fig. 2. Side Elevation of Machine

too many uncertainties were introduced by the friction of the pencil and other conditions and this feature was finally abandoned.

20 The specimen holder is shown in section in Fig. 4. The specimen is held in the hardened steel bushing *O* in end of lever *L*, which receives its motion through connecting rod *F* to which it is attached by studs *M* and *N*. The specimen is held against the lapping plate by the pressure of the weights shown in the figure, which is transmitted to the specimen through the yoke *E*, screw *S* and pin *J*. These parts are supported by a tube *A* held by the split block *B* which in turn is clamped to the connecting rod *F*.

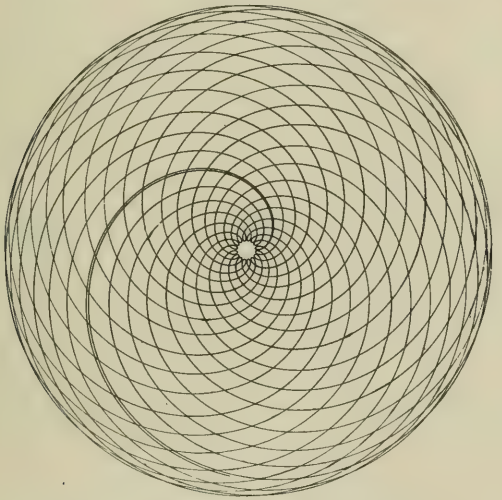


Fig. 3 Outline Traced by Machine

21 The nut *D*, through which passes the screw *S*, is of tool steel, hardened, ground and lapped to a smooth working fit in the tube. At *K* is a hardened steel plug, which is also a smooth working fit in the tube. This plug has a conical seat at each end in which bear the tapered ends of screw *S* and pin *J*. The object of this construction is to allow a slight lateral movement of the specimen without disturbing the alignment or in any way increasing the friction of the moving parts in the vertical tube. A perfectly free vertical motion is thus obtained whereby the weights can follow up the wear of the specimen with practically no friction.

22 The bushing *O* which carries the specimen is counterbored in order that any side thrust may be brought as near the lower

surface of the specimen as possible. In order to move the specimen from under the tube for examination or removal, the knurled nut N is loosened, thus permitting the arm L to be turned about the stud M.

23 It was the original intention to have the specimen carried directly in the vertical tube, but after some experience with this and several other forms they were discarded. The present holder

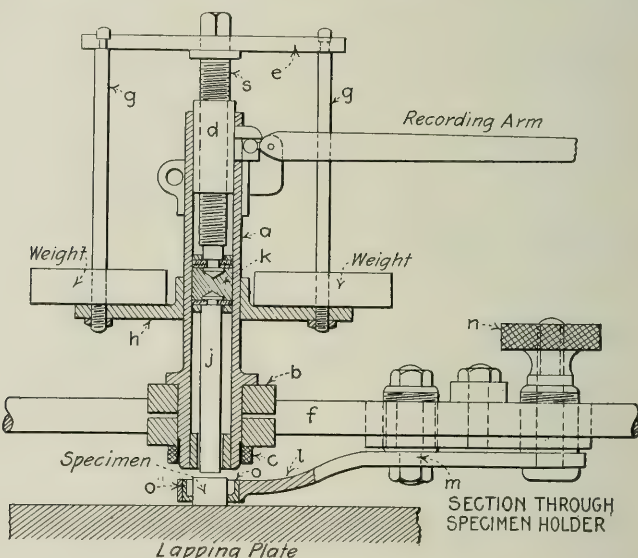


Fig. 4 Section through Specimen Holder

was developed as a result of experience gained during the preliminary stages of the work.

THE LAPPING PLATE

24 The lapping plate is shown in section in Fig. 5. The lap surface is at A. A gray iron plate, cast originally ½ in. thick and finished down to 3/8 in. thick, is held to the lower plate B by means of screws. The outer rim C is also fastened by screws and is removable.

25 At first it was attempted to use a plate cast in one piece, but it was found that it was more porous near the center than at the edge and further that it was impracticable to face the plate in a lathe without leaving pit marks in the surface. Obviously these

conditions would produce unsatisfactory results and it was therefore decided to use a removable upper plate of uniform thickness which would be practically uniform in texture and could be readily finished to a true surface, clear to the edge, by grinding.

26 Five plates were cast from the same heat, so if one or more developed defects or was worn out, another of the same metal could be substituted. The plates were of a good grade of foundry iron, but no attempt was made to get a special mixture.

27 The copper and steel laps were built up the same way. Each consisted of a cast iron backing plate faced with its proper material.

28 The copper plate was made of plate copper 1/4 in. thick. Since this was too thin to be tapped into, it was secured to the cast plate by means of solder.

29 The steel plate was made of fire box steel 1/4 in. thick and secured in the same manner as the copper plate. Like the cast iron plate, the surfaces of these were finished by grinding.

DISTRIBUTOR

30 The distributor, or wiper, is an important feature of the machine. Referring again to Fig. 2, this will be seen at *T*, and is shown more in detail in Fig 6.

31 It was essential that there be a uniform distribution of the charge of abrasive over the entire surface of the plate. Centrifugal force was depended upon to work the charge from the center of the plate outward. A wiper, consisting of a strip of wood resting on the plate and inclined at an angle of 15 deg. to a radial line from the center, was counted on to shear the charge back toward the center. At times this worked finely, leaving enough of the charge pass under the wiper to give an even and uniform distribution. At other times the wiper would apparently adhere tightly to the plate, wiping it nearly clean and bunching the charge in the center. Notches were cut in the underside of the strip of wood, through which a portion of the charge could always flow. This helped very materially, but the distribution was further improved by giving motion to the wiper. This was effected through the medium of an eccentric *R* placed on the shaft *D*. To prevent an accumulation of part of the charge around the inner surface of the outer ring, a small auxiliary wiper was placed as shown at *Q*. Details of the notched piece of wood are shown in Fig. 7.

TEST SPECIMENS

32 The test specimens were of hardened tool steel. It was first attempted to use a hollow specimen of the form shown in Fig. 8, in order to secure uniformity in hardening and to reduce the tendency to rock while being moved over the lap surface. After many trials this form was given up. It seemed absolutely impossible to duplicate runs with any degree of certainty. The cause of this

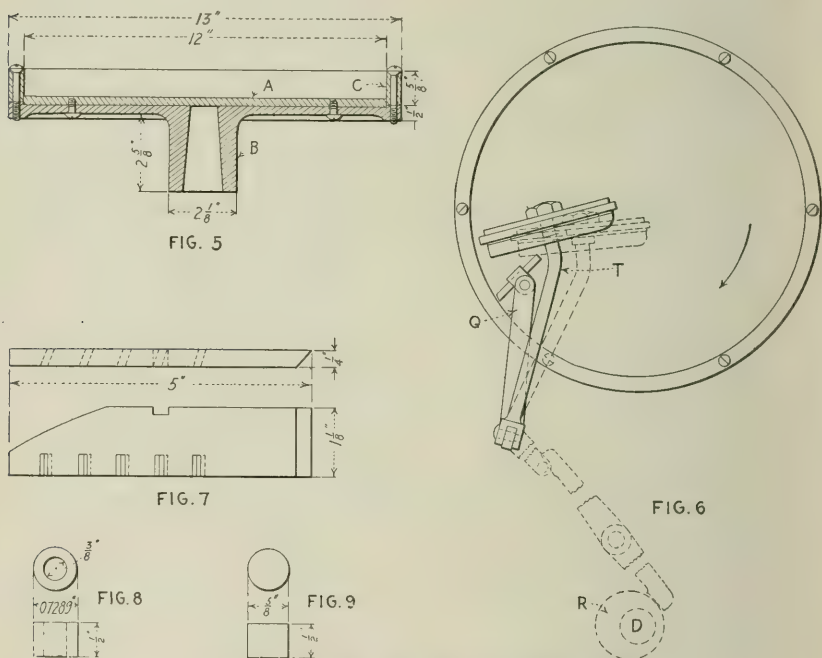


Fig. 5 Section through Lapping Plate
Fig. 6 Details of Distributor
Fig. 7 Distributor Shoe
Fig. 8 Test Specimen, Form Rejected
Fig. 9 Test Specimen, Form Used

is not exactly clear, but it may be due to the fact that the surface in contact with the plate being perfectly flat and the edges perfectly square and sharp would allow the specimen to shear the abrasive ahead of it instead of riding over it.

33 The specimens finally used, as shown in Fig. 9, were made of 5/8-in. drill rod. Fifty-five pieces 1/2 in. long were cut from the

same bar and numbered consecutively. They were hardened by heating in the muffle of a gas furnace, the temperature of which was regulated by a pyrometer, and quenching in clear water to which salt had been added to the amount of 3 lb. to the gallon.

SCOPE OF TESTS

34 It was not the intention to try out all the different abrasives on the market. Three were selected as being representative, namely, Naxos Emery, obtained from the Safety Emery Wheel Co., Springfield, Ohio; Carborundum, direct from the Carborundum Company, Niagara Falls, and Alumdum, from the Norton Company, Worcester, Mass.

35 All the tests were carried out with abrasive No. 150. Each of the abrasives was tried with seven different lubricants, five different pressures, and three different laps. The lubricants were lard oil, machine oil, kerosene, gasoline, turpentine, alcohol, and soda water.

36 Starting a series of tests, say with emery as the abrasive and with cast iron lap, the first test was made with lard oil and with a pressure of 5 lb. per sq. in. on the specimen. The pressure was then increased to 10 lb. per sq. in., other conditions remaining the same, and another run made. The pressures were then increased to 15, 20, and 25 lb., giving a group of five runs with lard oil.

37 Machine oil was then substituted for lard oil and a like group of tests made, after which tests were made with the other lubricants in the same way. This gave for cast iron-emery a series of 35 tests.

38 Carborundum was next substituted for emery and the same number of tests repeated. This was followed by a like series with alundum, making the total number of tests with cast iron lap 105.

39 The cast iron lap was then replaced by one of steel and a second series of 105 tests run with the steel lap. This was followed by a like series with the copper lap. Therefore, for making comparisons of the action of the three abrasives and also for the three lap materials, cast iron, copper, and steel, we have 105 tests of each.

DETAILS OF TESTS

40 The quantity of abrasive used for each test was as follows:

3 grams of emery
2.46 grams of alundum
2.40 grams of carborundum.

These weights gave equal volumes. This was considered to give a fairer test than if equal weights had been taken, because it gave equal density or the same number of grains of the abrasive per square inch of plate surface. The charge was weighed for each test.

41 When making tests with lard and machine oils, 7 cc. were used. This was applied at the beginning of the test and no further

Test No. 92 date 3-12-13 Observer - KNIGHT

ABRASIVE - Emery - Grade 150 - Lubricant M. Oil Pressure 15 lbs.					
Reading of Counter	Reading of Counter	Revolutions	Weight beginning of run	Weight end of run	Weight ground off
21000	21500	500	19330	19240	90
	22000	500		19186	54
	23000	1000		19139	47
	24000	1000		19110	29
	25000	1000		19090	20
			19330 19090		90 144
			240		191 220
					240

Fig. 10 Blank Used in Recording Tests

additions made. With the light and volatile liquids 7 cc. was too much to start with, as the specimen would get down to the lap surface and shear the abrasive ahead of it. With these liquids, the test was started with 3 cc. and then additions made from time to time to make up the loss from evaporation. Before starting a run, the charge of abrasive and lubricant was distributed with the fingers as uniformly as possible over the surface of the lap.

42 A test was continued until the crank which moved the specimen over the plate had made 4000 rev. At the end of 500 rev., the specimen was removed, cleaned with gasoline, and weighed. This was repeated at the end of the next 500, and then for each 1000 until the 4000 rev. were completed.

43 The log of a single test is shown in Fig. 10, while Figs. 11 to 17, inclusive, show the plotted results of the individual tests of the cast iron-emery series. As plotted, the ordinates represent the amount in milligrams ground from the specimen, abscissa the number of revolutions of the crank which swept the specimen over the plate.

44 The individual tests of this series are shown plotted not because they are better or worse than the others, but to show at a glance the general form of individual curves, how the shape varied with the pressure, and the degree of consistency in the various tests.

45 A summary of all the results is given in Table 1 herewith.

TABLE 1 SUM OF AMOUNTS GROUND FROM SPECIMENS WITH PRESSURES OF 5, 10, 15, 20, AND 25 LB. PER SQ. IN.

		Machine Oil	Lard Oil	Kerosene	Gasoline	Turpentine	Alcohol	Soda Water	Total
Cast Lap	Emery	1320	1673	3324	3955	2336	2392	3105	18105
	Alundum	1849	2313	3687	4291	3230	3251	3112	21733
	Carborundum	2825	3340	4230	4520	4458	4427	3873	27673
	Total	5994	7326	11241	12766	10024	10070	10090	67511
Steel Lap	Emery	1744	2460	2720	3034	2560	2608	2839	17965
	Alundum	1800	2537	3622	3627	3400	3388	3338	21712
	Carborundum	4199	4649	3805	3980	3983	3527	4045	28188
	Total	7743	9646	10147	10641	9943	9523	10222	67865
Copper Lap	Emery	3250	3454	3756	3813	3598	3961	3780	25612
	Alundum	3971	4065	3763	3960	4171	4097	4472	28499
	Carborundum	4148	4540	3692	3724	4251	4081	4210	28646
	Total	11369	12059	11211	11497	12020	12139	12462	82757
	Grand total for each lubricant	25106	29031	32599	34904	31987	31732	32774	

COMPARISON OF RESULTS

46 In considering the general results, the various factors are so inter-related that a discussion of one naturally becomes involved with all the others, hence more or less repetition is unavoidable.

47 Obviously, it is impracticable to compare each individual result with every other result. The plan has therefore been adopted of combining the five curves of the different pressures into one curve. This is called the master curve for that particular combination, and is effected by simply summing up the values of the ordinates for different points on the curves and using these values

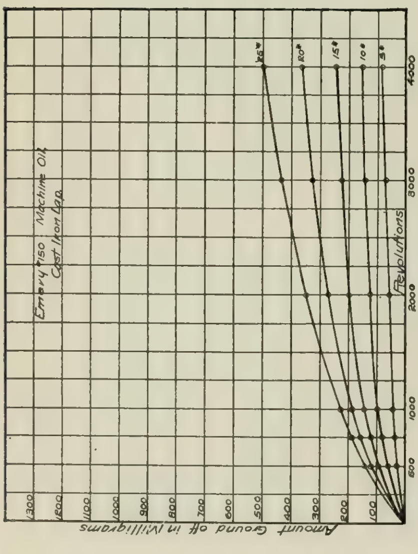


FIG. 11

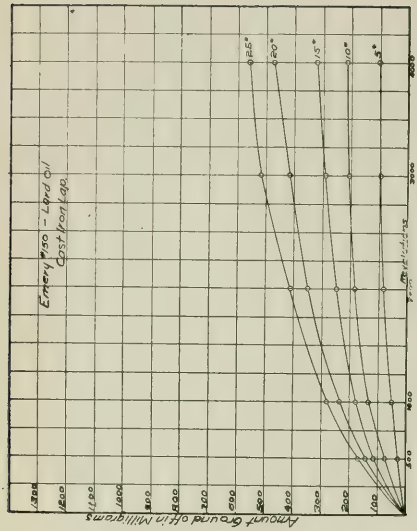


FIG. 12

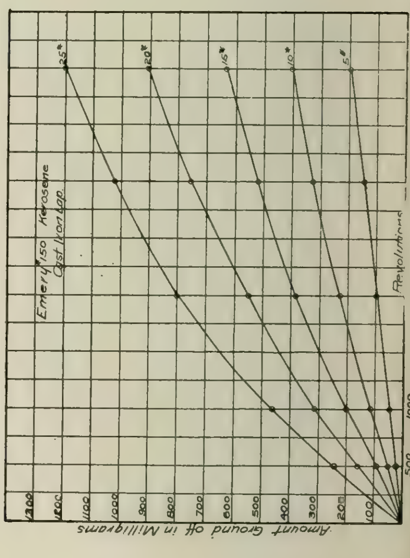


FIG. 13

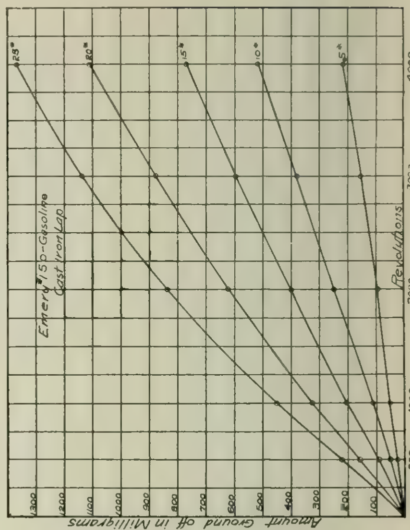


FIG. 14

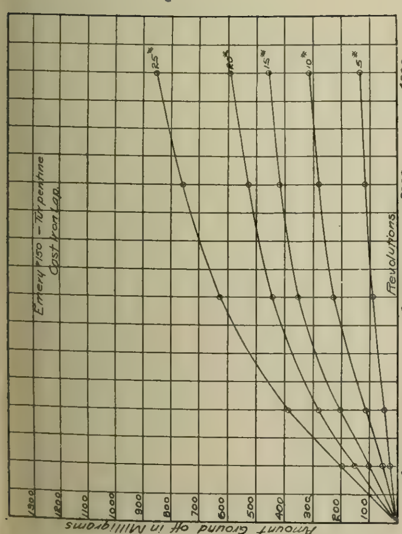


Fig. 15

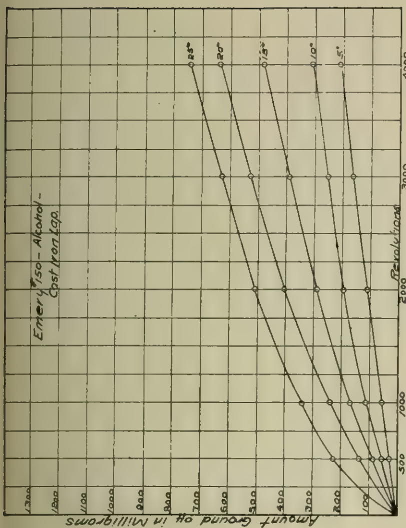


Fig. 16

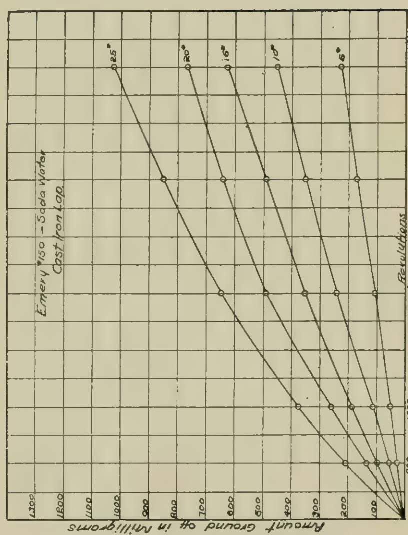


Fig. 17

Curves of Cast Iron-Emery Series Reproduced to Show Characteristics of Tests

in plotting the master curve. If these values were divided by five, the result would be an average curve of the five pressures. The curves as they stand, without such division, are practically the same thing.

48 This method is not strictly correct, because it assumes the curves to be of the same form and that the rate of cutting is proportional to the pressure. This latter is very nearly true but the shape of the curves changes somewhat with the pressure. In general, the curve starts off concave upward and at some point in the run changes to convex. This change takes place at different distances from the origin. It is further out for the light pressures and approaches the origin as the pressure is increased. This condition is clearly indicated in the set of curves for gasoline, Fig. 14. Since, however, all results are combined in the same way, it is thought that this method forms a fair basis of comparison. The X marks on the curves indicate about where the maximum rate of cutting is reached.

49 It will be understood then that each of the comparative curves for the different lubricants, abrasives, and lap materials is the combined curve of five separate runs.

50 *Lubricants.* The action of the different lubricants presents an interesting study. The same lubricant acts differently with the different abrasives and again differently with different laps. It might be surmised that the main difference would be due to changes in viscosity or to the lubricating properties of the various lubricants. There is no doubt that these are important factors, but it is equally certain that they are not the only ones.

51 Taking the results of the emery-cast-iron series of tests alone, as shown plotted in Fig. 18, it would seem that the change in the viscosity and lubricating properties would offer a reasonable and fairly complete explanation of the difference in their behavior.

52 Gasoline, which is lowest in these respects, has the highest rate of cutting. It will be noted, too, that its rate of cutting is well maintained, being nearly as high at the end of 4000 rev. as at the beginning. Next is kerosene, the rate of cutting of which is high, but which shows slightly more of a decreasing rate as the end of the run is approached. Soda water is below that of kerosene, but maintains its rate of cutting more nearly like gasoline. Alcohol and turpentine have about the same rate of cutting at the start as soda water, but decrease more rapidly as the run proceeds. Both these liquids have

peculiarities which will be considered further while discussing individual lubricants.

53 The rate of cutting for both lard and machine oil drops off very rapidly. At the end of a run, that for machine oil is about 166 per 1000 rev., while that for gasoline is about 850, these two standing at the extremes of the range.

54 What appears to happen is this: As the grinding proceeds the emery is constantly reduced to a finer powder and the charge is being contaminated with material ground from the specimen and the lap surface. With a lubricant like gasoline there is no muck formed, the charge remains comparatively clean and the thickness of the film of gasoline is so little that the specimen may follow up the reduction in size of grain of abrasive and, hence, a nearly uniform rate of cutting is maintained.

TABLE 2 CAST IRON LAP

	Emery		Alundum		Carborundum	
Highest	Gasoline	3955	Gasoline	4291	Gasoline	4520
Lowest	Machine oil	1320	Machine oil	1849	Machine oil	2825
Difference		2635		2442		1695

55 On the other hand, with the heavy oils, as the grinding proceeds the charge becomes muck-like, the lubricant is thickened and the specimen rides on the thickened oil film. When the grains have been reduced in size to a little less than the thickness of the oil film, the cutting action almost ceases.

56 Passing, however, to the alundum-cast iron series, a comparison of the lubricants of which is shown in Fig. 19, there is not so much difference in their rate of cutting as with emery. Lard and machine oil are in the same relative position to each other and to the other lubricants, but they have approached more nearly to the others in rate of cutting. Reference to Fig. 20 will show that the difference further disappears when carborundum is used as the abrasive material. Table 2 is presented to further emphasize this. Of the seven lubricants used, this table shows the ones which gave the highest and the lowest values when used with the cast iron lap and different abrasives.

57 The curves for the steel lap and the copper lap are shown in Figs. 21 to 26. An examination of these will reveal a further

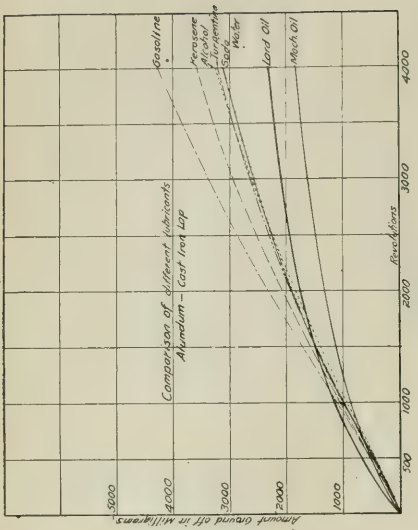


FIG. 19

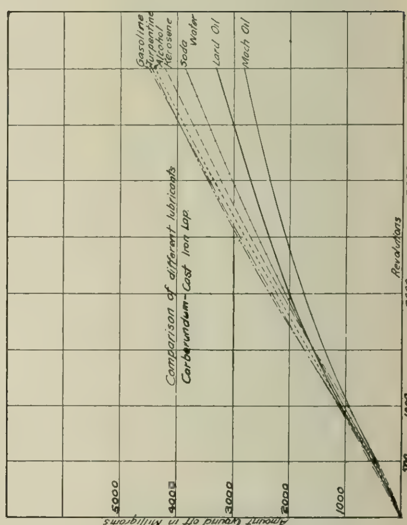


FIG. 20

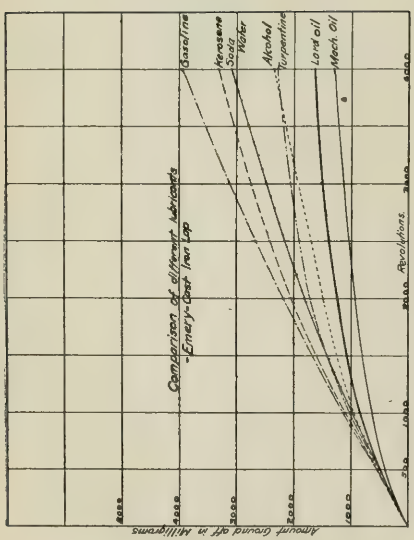


FIG. 18

COMPARISON OF DIFFERENT LUBRICANTS ON CAST IRON LAP

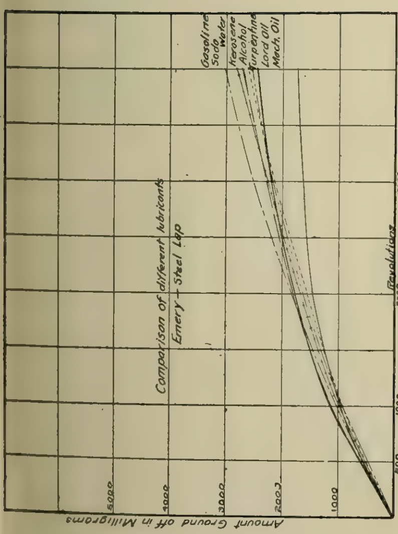


Fig. 21

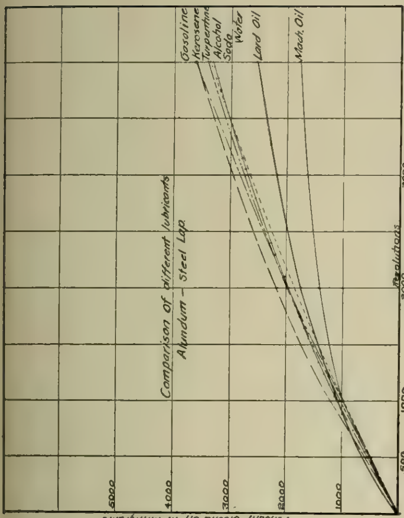


Fig. 22

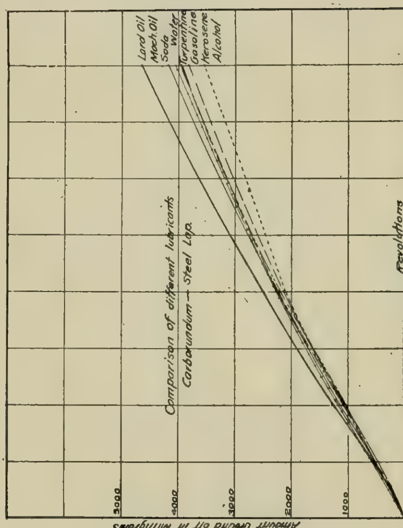


Fig. 23

Comparison of different Lubricants on Steel Lap

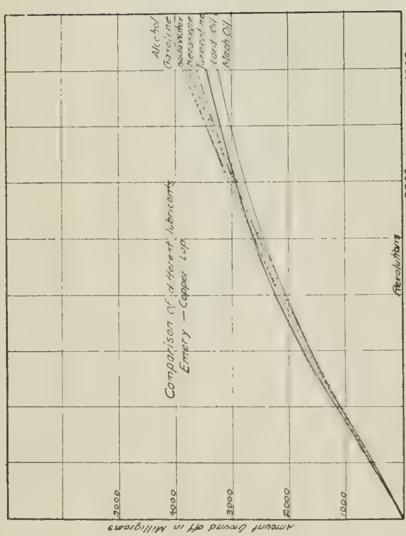


Fig. 24

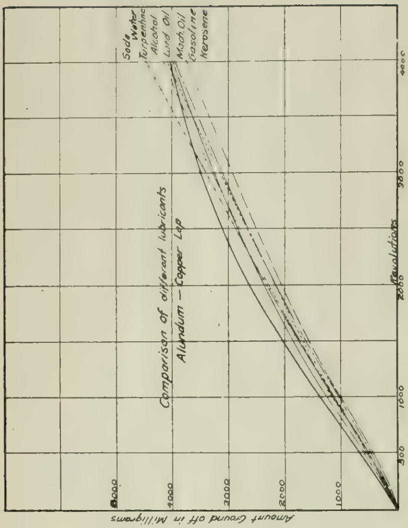


Fig. 25

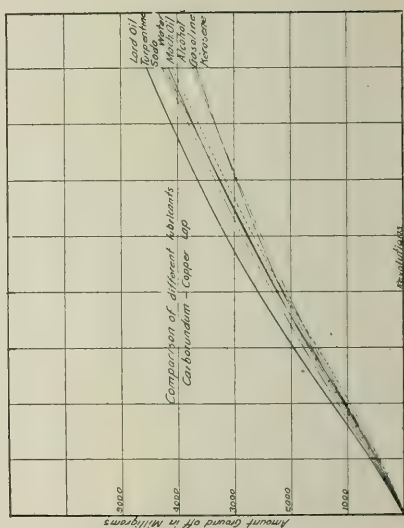


Fig. 26

Comparison of different Lubricants on Copper Lap

closing-in of the curves, or, in other words, a nearer approach to each other in rate of cutting. Lard and machine oil take on higher values. These two oils, with emery on the cast iron lap, give lower values than any of the other lubricants, while the same two, with carborundum on the steel lap, give higher values than any other of the lubricants. It seems evident, therefore, that factors other than viscosity and lubricating properties play an important part in the rate of cutting.

58 As a possible explanation, it is suggested that the lubricant, together with the material ground from the specimen and the lap surface, forms kind of a matrix or bonding material for the abrasive, and that the rate of cutting is largely dependent on the nature of this matrix. Evidently there will be a different matrix formed with each different combination of lap, abrasive, and lubricant.

59 It is probable, too, that there is some property of the lubricants which enables some to cause a sharper or cleaner cutting action than others. We know that for thread cutting and many other machine tool operations, a cutting tool used with lard oil takes a cleaner cut and leaves a smoother surface than when used with machine oil. There is evidence that some such property is present and exerts an influence on the results obtained with the different lubricants.

INDIVIDUAL LUBRICANTS

60 *Lard and Machine Oil.* On account of their differences and yet of their similarity of action, lard and machine oil will be considered together. It is to be observed

- *a* That in tests under all conditions, their curves are of the same form and follow each other closely.
- *b* That lard oil without exception gives the higher rate of cutting.
- *c* That in general the initial rate of cutting is higher than with the lighter lubricants, but falls off more rapidly as the run proceeds.
- *d* That both the highest and lowest results of the whole number of tests were obtained with these two lubricants. The lowest with machine oil, emery-cast iron lap, with lard oil a little above it; the highest with lard oil, carborundum-steel lap, with machine oil a little below it. That is, while

they have maintained the same relative position to each other, both have advanced until, with the steel lap and carborundum, they lead all other lubricants in rate of cutting. Compare the curve, Fig. 18, with those of Fig. 23.

61 Table 3 shows this progressive increase in the values obtained with the different combinations:

TABLE 3 AMOUNT GROUND FROM SPECIMEN WITH MACHINE AND LARD OIL FOR THE DIFFERENT COMBINATIONS OF LAP AND ABRASIVE

	Machine Oil			Lard Oil	
Cast Lap	Emery	1320	Cast Lap	Emery	1673
	Alundum	1849		Alundum	2313
	Carborundum	2825		Carborundum	3340
Steel Lap	Emery	1744	Steel Lap	Emery	2460
	Alundum	1800		Alundum	2557
	Carborundum	4199		Carborundum	4649
Copper Lap	Emery	3250	Copper Lap	Emery	3459
	Alundum	3997		Alundum	4065
	Carborundum	4148		Carborundum	4540

62 *Gasoline and Kerosene.* On the cast iron lap gasoline shows the highest results of any of the lubricants tested. It is not so good on copper and still less so on steel. Taking into account all three abrasives, its relative value on the different laps is as follows:

Cast iron 127 Copper 115 Steel 106

63 Contrasting these results with those obtained with lard and machine oil, we find that with them there is an increase in the rate of cutting with the steel and copper lap, whereas with gasoline there is a decrease.

64 Kerosene shows more nearly the characteristics of gasoline than of the heavier oils. Like gasoline, it gives the best results on cast iron and the poorest on steel. It does not work so well with carborundum on the copper lap. While the result with this combination is not so low as some others, it is low for carborundum, because, in general, this gave higher results than the other abrasives. In fact, for the entire series of 315 tests, there were but two instances in which the values obtained for carborundum were not higher than those with emery, and these two were with gasoline and kerosene on the copper lap. Mention has already been made of the discoloration of

the copper plate when these liquids were used. It seems as if some of the abrasive was worked into the surface and then smoothed down, giving, instead of a clean copper surface, one more or less hard and glazed. This was more in evidence with the higher pressures and no doubt caused a falling off in the rate of cutting. However, just why the effect should be more pronounced with carborundum than with the other abrasives is not clear.

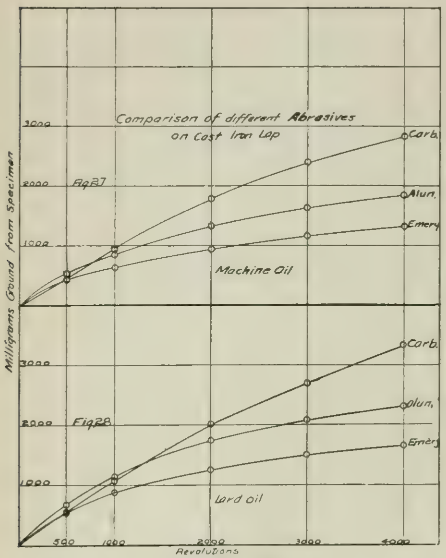
65 *Turpentine and Alcohol.* There is no evidence to show that turpentine possesses any superior advantage over the other lubricants. On any lap it does good work with carborundum. With emery it does fair work on the copper lap, but with emery on the cast iron and steel lap it is distinctly inferior.

66 When used on cast iron or steel with emery, the charge soon becomes pasty or muck-like. The resultant residue is very dark, almost black, and at the end of a run seems fine and smooth with very little of its gritty nature left. As a considerable portion of turpentine evaporated during the course of a run, and the loss made up by fresh additions, it was at first thought that the thickening of the charge was due to a gummy residue being left by such evaporation. However, with carborundum the charge showed no such thickening, the residue being more like that formed with machine oil. This accounts for the better showing turpentine makes when used with carborundum.

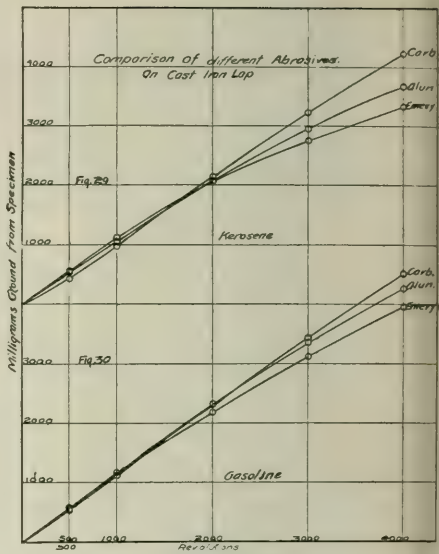
67 Alcohol in some ways acts very much like turpentine. It also gives the lowest results with emery on the cast iron and steel laps. Like turpentine, the residue at the end of a run is fine and smooth. But the residue instead of being black and pasty is of a deep reddish brown color and inclined to be foamy or spongy.

68 Alcohol and turpentine were the only two lubricants that gave any evidence of having a solvent or chemical action on the abrasive, and these with emery only. Since, however, neither showed any particular merit for this work over other lubricants, it was thought useless to pursue that phase of the subject any further.

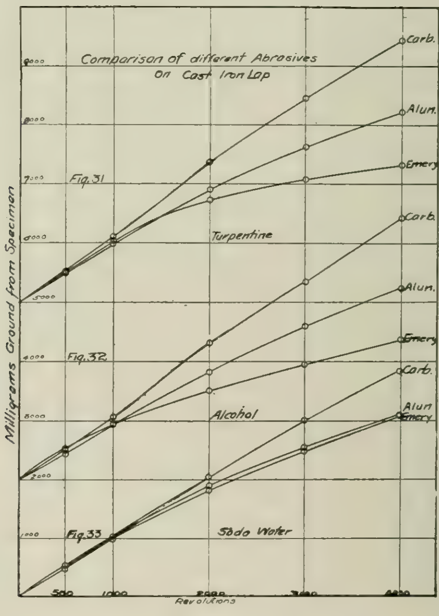
69 *Soda Water.* Soda water gives reasonably good results with almost any combination of lap and abrasive. Referring again to the comparison curves for the lubricants, Figs. 18 to 26, it will be seen that it maintains a fairly constant position intermediate between the other lubricants. While it is seldom the best, it is never the worst. It does its best work on the copper lap and poorest on steel, although there is not much difference between its work on the cast iron and



FIGS. 27–28

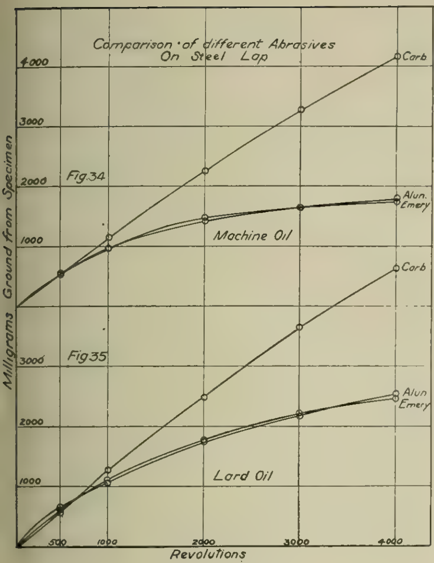


FIGS. 29–30

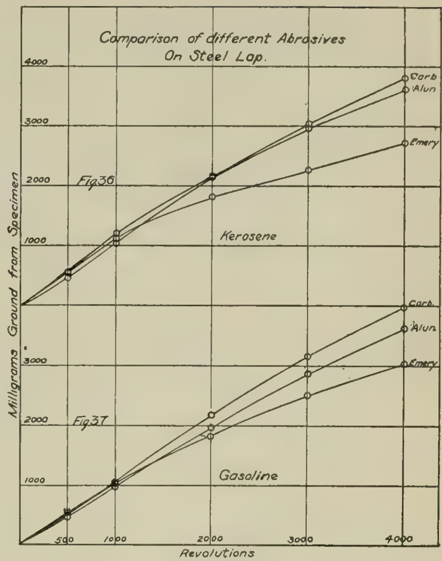


FIGS. 31–33

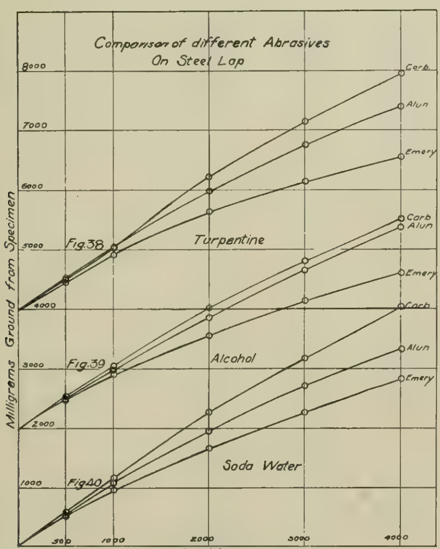
COMPARISON OF DIFFERENT ABRASIVES ON CAST IRON LAP



Figs. 34–35

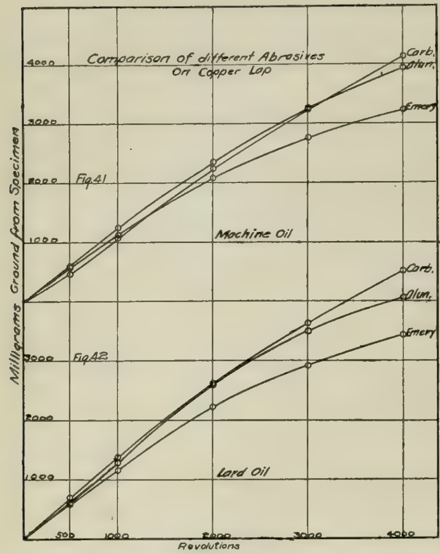


Figs. 36–37

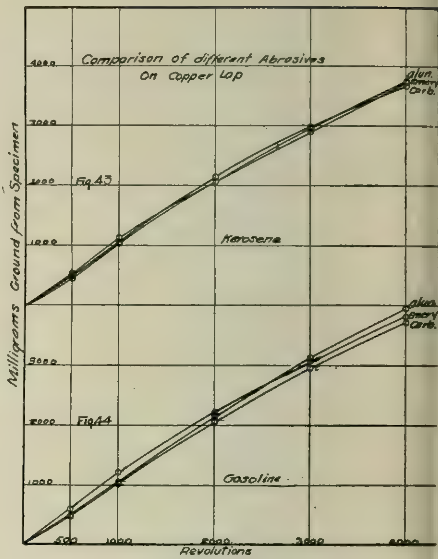


Figs. 38–40

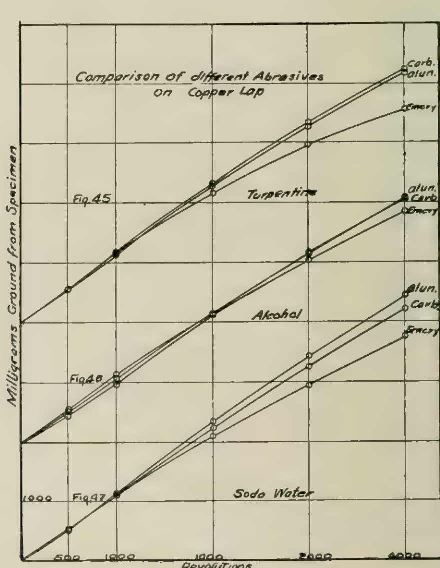
Comparison of different Abrasives on Steel Lap



Figs. 41–42



Figs. 43–44



Figs. 45–47

Comparison of different Abrasives on Copper Lap

steel. On the cast iron lap it does better work than machine or lard oil, but not so good as gasoline or kerosene. There was one instance, that with alundum on the copper lap, in which soda water gave the highest results of any of the lubricants used with that particular combination. It is not a nice liquid to work with. The residue is muck-like and sticky. When dry it forms a hard, crusty substance. While undesirable from this standpoint, as far as results go and as to first cost, it should rank ahead of turpentine and alcohol.

THE ABRASIVES

70 It may be well to call attention to the fact that emery and alundum are similar abrasives, both being aluminum oxides of the form Al_2O_3. Emery is a natural product, more or less contaminated with iron or other impurities. Alundum is an artificial product and in general, of greater purity than the natural product. Carborundum, on the other hand, is an entirely different material, being a carbide of silicon, SiC. Naturally, then, emery and alundum might be expected to show more nearly the same characteristics, while carborundum would deviate more or less for them.

71 That this is true, an examination of the curves, Figs. 27 to 47, will show. These curves show graphically the rates of cutting for the three abrasives for all the different combinations of lap and lubricant.

72 It will be noticed that carborundum usually starts off at a lower rate than the other abrasives, but once started, its rate is maintained better. Its curve, in general, is more nearly a straight line. The charge or residue as the grinding proceeds remains cleaner and sharper and is not inclined to become pasty or muck-like, as is so frequently the case with emery.

73 Alundum, both as to its rate of cutting and cleanliness of residue, is, in general, intermediate between carborundum and emery.

74 Taking the total amount of steel ground from the specimens with each of the abrasives as a basis of comparison, they stand as follows:

Carborundum 84,507 Alundum 71,944 Emery 61,682

75 These figures are for all three laps. Divided up according to the amounts ground off with each individual lap, the results are as follows:

TABLE 4 AMOUNTS IN MILLIGRAMS GROUND FROM SPECIMENS WITH DIFFERENT COMBINATION OF LAP AND ABRASIVE

Cast Lap	Emery.......18105	Steel Lap	Emery....17965	Copper Lap	Emery...25612
	Alun........21733		Alun......21712		Alun....28499
	Carb........27673		Carb......28188		Carb....28646

76 It is to be observed that there is a greater difference in the action of the abrasive with the cast iron and steel lap than with the copper. With the copper lap, carborundum shows but little gain over the cast iron and steel, while with emery and alundum, the gain is considerable.

77 It may be pointed out, again, that the evidence all the way through tends to the conclusion that there is for each different combination of lap and lubricant a definite size grain of abrasive that will give maximum rate of cutting. With all, except the two heavy lubricants, some reduction in size of grain below that used in the tests (No. 150) seemed necessary before the maximum rate of cutting was reached. But this reduction in size goes on continuously and soon passes below that which gives maximum cutting. It is at the point of passing this definite size that the curve changes from concave to convex, or, in other words, the cutting changes from an increasing to a decreasing rate. As before explained, the change depends on all four factors, namely, pressure, abrasive, lubricant, and lap material.

78 Emery appears to be more brittle and passes through the change quicker than the others, with alundum next and carborundum the least susceptible to such a change. This accounts for the initial rate of cutting with carborundum being lower than the other abrasives.

COMPARISON OF THE LAPS

79 The form and material of laps have already been given. Their hardness, as determined by the research department of the Westinghouse Electric and Manufacturing Co., was as follows:

By the Brinell Method

Cast iron 109	Steel 87	Copper 43.6

By the Sclerescope

Cast iron 28	Steel 18	Copper 5

80 A comparison of the three laps with all combinations of abrasive and lubricant is given in the set of curves, Figs. 48 to 68.

81 The total amount ground from the specimen with each of the three laps was:

With cast iron	67511
With steel	67865
With copper	82757

This shows that taking the whole number of tests as a criterion, there is scarcely any difference between the steel and cast iron, but that copper does somewhat the best work. Since, however, there is a great difference between the highest and lowest values obtained with each individual lap, it would seem more logical in comparing their relative merits to compare the highest values obtained with each. On this basis they stand in this order:

Steel with carborundum,—lard oil	4649
Copper with carborundum,—lard oil	4540
Cast iron with carborundum,—gasoline	4520

Here, again, there is not so much difference, but it shows that with the proper abrasive and lubricant, steel and cast iron are equally as good (for all practical purposes) as copper.

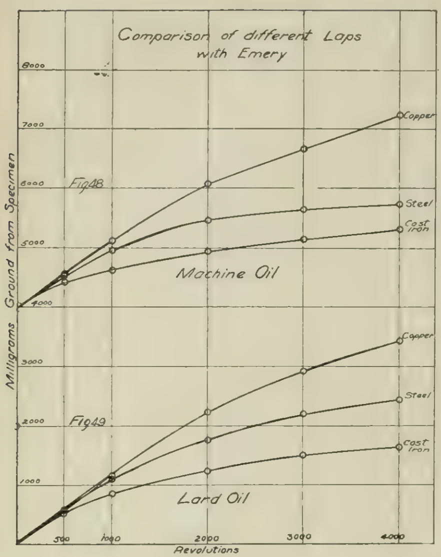
WEAR OF LAPS

82 One of the remarkable facts brought out was the great difference in wear of the laps both as regards material of which they were made and by the different abrasives. The wear on all laps was about twice as fast with carborundum as with emery, while with alundum the wear was about one and one-fourth times that with emery. On an average the wear of the copper lap was about three times that of the cast lap. This is not absolute wear, but wear in proportion to the amount ground from the specimen. Table 5 shows this very clearly.

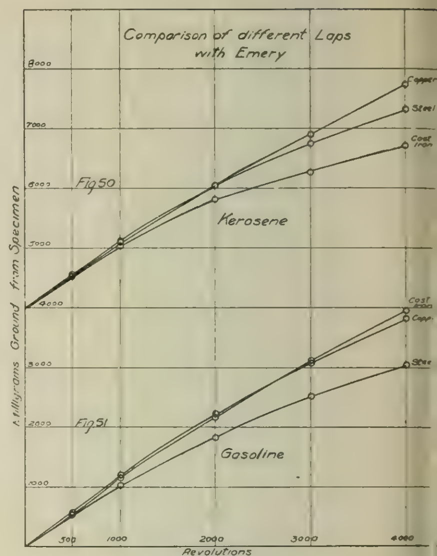
TABLE 5 AMOUNTS GROUND FROM THE LAP SURFACE FOR EACH 100 MILLIGRAMS GROUND FROM THE SPECIMEN

Emery	Alundum	Carborundum	Total
Cast iron........ 81.2	118	158	357.2
Steel...........114	149	190	453
Copper.........233	295	410	938

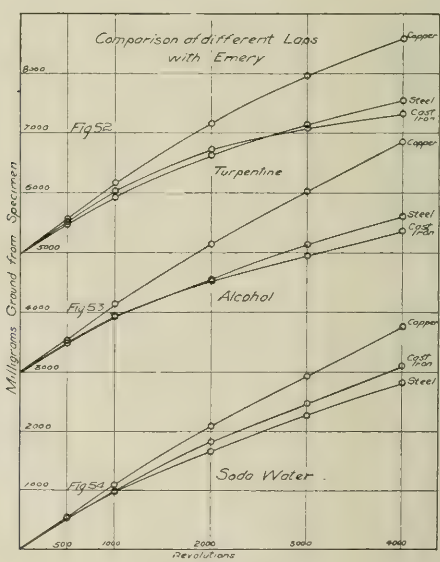
83 Comparing the total wear of the laps with their hardness by the Brinell test, it is found that the wear is very nearly in inverse ratio to the hardness. Thus



Figs. 48–49

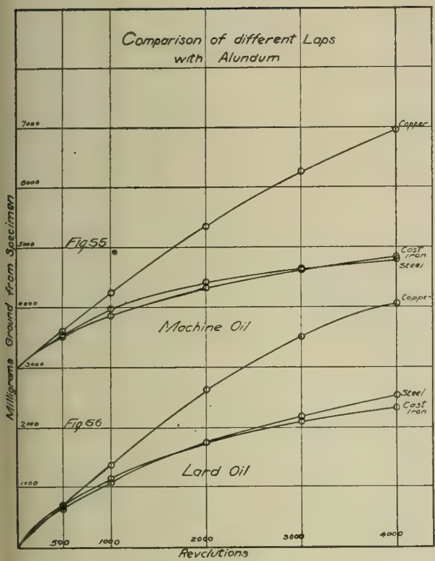


Figs. 50–51

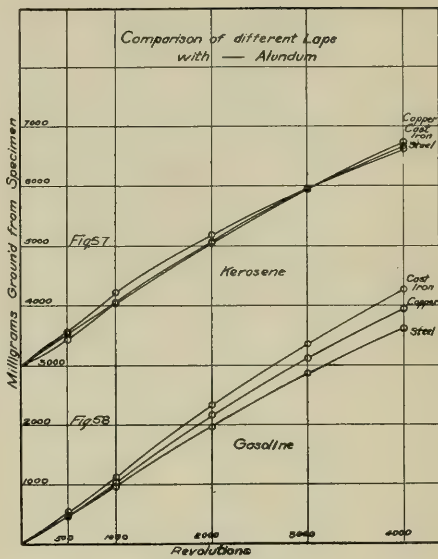


Figs. 52–54

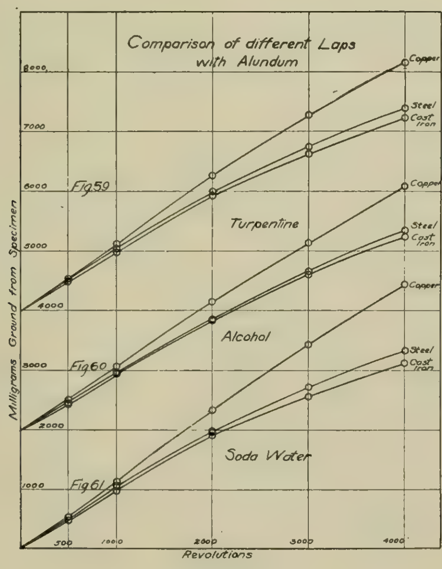
Comparison of different Laps with Emery



FIGS. 55–56

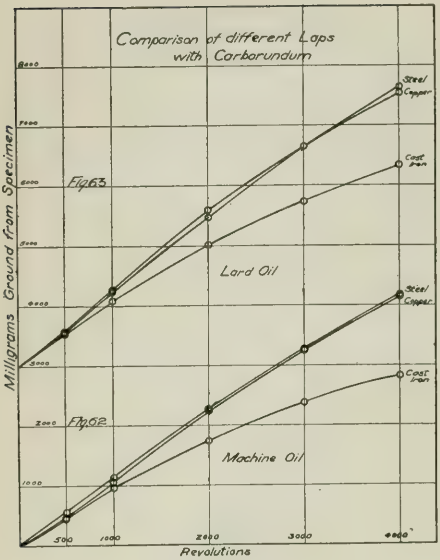


FIGS. 57–58

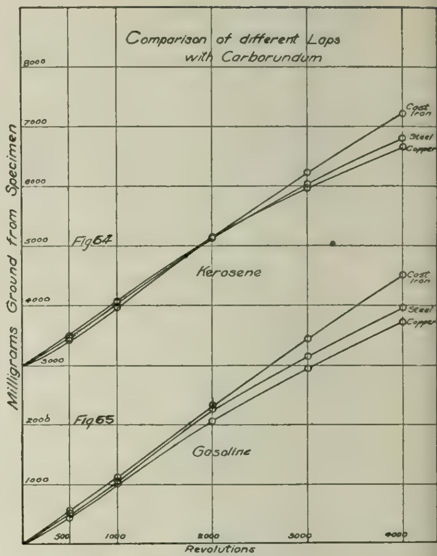


FIGS. 59-61

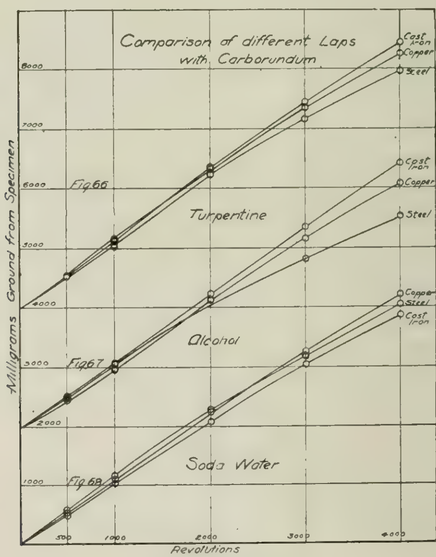
COMPARISON OF DIFFERENT LAPS WITH ALUNDUM



FIGS. 62–63



FIGS. 64–65



FIGS. 66–68

COMPARISON OF DIFFERENT LAPS WITH CARBORUNDUM

	Wear of Lap	×	Hardness	= a Constant
Cast iron.......	357.2	×	109	= 38,934
Steel	453	×	87	= 39,411
Copper	938	×	43.6	= 40,896

No such relation holds between the scleroscopic hardness and the wear.

84 As regards permanence of form, then, cast iron is altogether better than either steel or copper, and taking into account its first cost and that with proper abrasive and lubricant its rate of cutting is practically as good as copper or steel, it is far and away the best lap material.

85 From results obtained on the wear of the laps, it is evident that the theory of the lodgment of the abrasive in the softer lap surface of the lap is not well founded. The action appears to be more mutual between the surfaces. That is, while a grain is making a cut or scratch across the steel specimen, it is at the same time cutting one in the lap surface, and, encountering less resistance, cuts a longer and deeper scratch in the lap surface than in the hardened steel.

86 It is probable that carborundum, which is a hard, sharp abrasive, gets more of a "foot hold" in the hardened steel than the other abrasives and thus does more damage to the lap surface.

PRESSURE

87 Within the limits of the pressures used; that is, up to 25 lb. per sq. in., the rate of cutting is practically proportional to the pressure. That this is not strictly true is because of the change in size of grain as the grinding proceeds. There is an increasing rate for a time and than a decreasing one. The greater the pressure the quicker this change. During the early part of a run the rate of cutting is not only increased by additional pressure but takes on another increment, due to the change in size of grain. After the maximum rate has been reached, this increment is negative and hence the rate of cutting is not quite proportional to pressure.

88 The higher pressures, 20 and 25 lb. per sq. in., did not do so well on the copper lap as on the others. There was some evidence tending to show that for this lap the practical limits of pressure had been reached.

89 Of the 63 combinations tried out, the 15 giving best results have been selected and are presented in Table 6:

TABLE 6 COMPARATIVE VALUES OF THE BEST COMBINATIONS, TAKING EMERY-CAST IRON LAP AND MACHINE OIL AS UNITY

Carborundum—Steel lap —Lard oil	3.52
Carborundum—Copper lap—Lard oil	3.44
Carborundum—Cast lap —Gasoline	3.42
Alundum —Copper lap—Soda water	3.39
Carborundum—Cast lap —Turpentine	3.37
Carborundum—Cast lap —Alcohol	3.35
Alundum —Cast lap —Gasoline	3.25
Carborundum—Copper lap—Turpentine	3.22
Carborundum—Cast lap —Kerosene	3.20
Carborundum—Copper lap—Soda water	3.19
Carborundum—Steel lap —Machine oil	3.17
Alundum —Copper lap—Turpentine	3.15
Carborundum—Copper lap—Machine oil	3.14
Alundum —Copper lap—Alcohol	3.10
Carborundum—Copper lap—Alcohol	3.09

DRY LAPPING

90 Experiments on dry lapping were carried out on the cast iron, steel and copper laps used in the previous tests and also on one of tin made expressly for the purpose. Like the others, the tin lap was made up of a cast iron backing plate provided with a facing of block tin about ¼ in. in thickness.

91 Carborundum alone was used as the abrasive and a uniform pressure of 15 lb. per sq. in. was used on the specimen throughout the tests. In dry lapping much depends on the manner of charging the lap.

92 The first tests were made on the steel lap, charged by rubbing the abrasive into the surface with a cast block 3 in. by 2 in. With a small quantity of carborundum, *F*, and lard oil the surface was worked down until of a uniform slaty color and free from deep scratches or marks left by the grinder. It was then washed clean with gasoline and *used perfectly dry.*

93 Next the plate was charged in the same way but instead of being washed with gasoline, the surface was simply *wiped clean with waste.* This left the plate practically dry but with a light film of oil adhering to its surface.

94 The results of these tests are shown plotted in Fig. 69. It is to be noted that with the plate perfectly clean and dry the cutting drops off quite rapidly after the first 100 rev. At the end of 500 rev.

the total amount ground from the specimen was but 10.6 milligrams. The upper curve, Fig. 69, shows the results when the plate was wiped clean, but not washed with gasoline. In this case the amount ground off at the end of 500 rev. was 63 milligrams or 6 times as much as with the plate perfectly dry.

95 Experiments demonstrated that between these two extremes, *results of any magnitude could be obtained, depending on how thoroughly the free abrasive was removed from the lap surface.* When the lap is simply wiped clean there still remains a film of oil over its surface and this carries a certain amount of free abrasive. This can be readily demonstrated by allowing a few drops of gasoline to strike the plate. As the gasoline spreads, as it does rapidly, a dark fringe appears around its outer edge. This dark fringe is free abrasive. When the lap surface is washed thoroughly with gasoline all free abrasive is removed, leaving only that which is embedded in the surface as the active material.

96 For all subsequent tests the plates were washed thoroughly clean, in order that there should be no variation in results due to a varying amount of free abrasive on the lap surface.

97 It makes a difference, too, whether the abrasive is rubbed or rolled into the surface. For the purpose of comparison, each lap was charged in 4 different ways:

a By rubbing carborundum "F" into the surface with cast block.

b By rubbing carborundum No. 150 into the surface with cast block.

c By rolling carborundum "F" into the surface with steel roller.

d By rolling carborundum No. 150 into the surface with steel roller.

98 For each test three duplicate runs were made and the results averaged. These values are tabulated in Table 7 and are shown plotted in Figs. 70 to 73.

99 The greatest difference due to different charging is shown by the tin lap. When abrasive No. 150 is rolled into its surface the cutting is about two and one-half times as fast as when the same abrasive is rubbed in. Also it is about three times as fast as when abrasive "F" is rolled, and six times as fast as when "F" is rubbed in. The same condition holds true for the copper lap, but not to so great an extent. With this lap the difference between the highest and

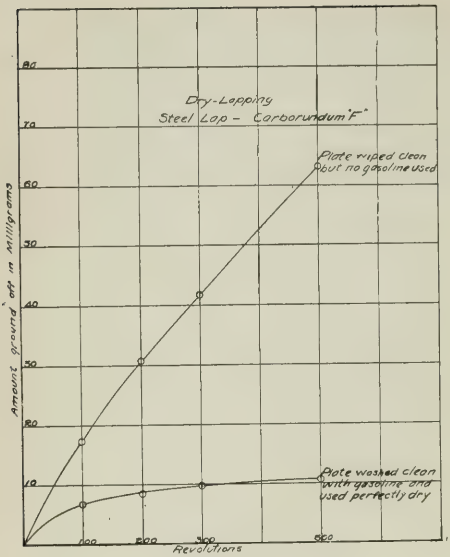
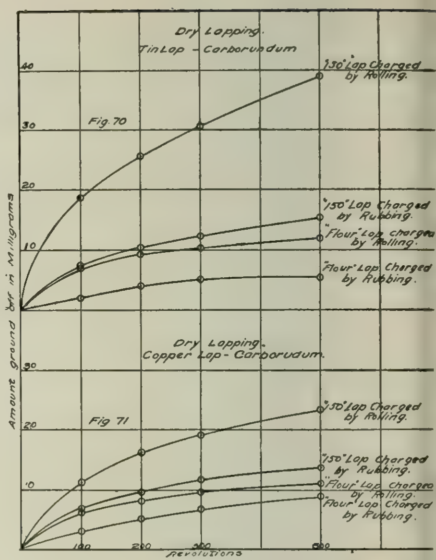
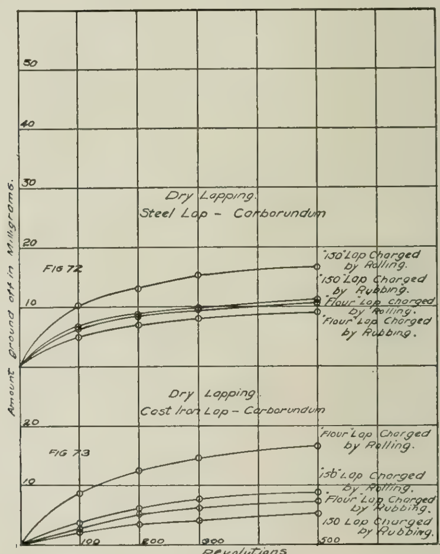


FIG. 69



FIGS. 70–71



FIGS. 72–73

DRY LAPPING, CARBORUNDUM, WITH STEEL, TIN, COPPER AND CAST IRON LAPS

TABLE 7 RESULTS OF TESTS ON DRY LAPPING

	Lap	Revolutions 100	200	300	500
		Milligrams ground from specimen			
Carborundum No. 150 lap charged by rolling	Cast	3.6	6	7.6	8.6
	Steel	10.3	13	15.3	16.6
	Copper	11.3	16.3	19	23.3
	Tin	18.6	25.6	30.6	39
Carborundum No. 150 lap charged by rubbing	Cast	2	3.3	4	5
	Steel	6.6	8.6	9.6	11
	Copper	6.6	9.6	11.6	13.6
	Tin	7.3	10.3	12.3	15.3
Carborundum "F" lap charged by rolling	Cast	8.6	12.6	14.6	16.6
	Steel	6.3	8.3	9.3	10.6
	Copper	6	8	9.6	11
	Tin	7	9.3	10.3	12
Carborundum "F" lap charged by rubbing	Cast	2.6	5	6	7
	Steel	5	7	8	9
	Copper	3	5	6.6	8.6
	Tin	2	4	5	5.3

lowest results is about 2.2 to 1, the highest being for No. 150 rolled in, the lowest "F" rubbed in. Rolling a charge of No. 150 abrasive into copper, then, is less effective than rolling into tin. On the steel lap it is still less effective, while on the cast lap this method of charging is least efficient of all.

100 This condition is clearly indicated by the curves in Fig. 74. For these all laps were charged by rolling No. 150 carborundum into the surfaces. With the cast lap, however, the best results were obtained when charged by rolling with grade "F."

101 It thus appears that with soft and ductile material like copper and tin the best results are to be obtained by rolling a comparatively coarse abrasive into the surface, but that with a harder and more brittle material like cast iron a finer grade should be used.

COMPARISON OF THE WET AND DRY METHOD

102 It must be evident that with so many different results, a comparison between the wet and dry methods is more or less unsatisfactory. In dry lapping the rate of cutting decreased rapidly after the first 100 rev. of the machine—much more rapidly than with the wet

method. It seems no more than fair, then, in making comparisons to consider the amounts ground off during the first 100 rev. Further, the highest result obtained with each lap is taken as the basis of comparison. With these data, it is found that with the tin lap, charged by rolling carborundum No. 150 into the surface, the rate of cutting, dry, approaches that of the wet. With the other laps, the rate for dry is about ½ that of the wet. Table 8 exhibits this:

TABLE 8 COMPARISON OF WET AND DRY LAPPING: PRESSURE, 15 LB.; ABRASIVE, CARBORUNDUM; 100 REV. OF MACHINE

	Best results with			
	Cast lap	Steel lap	Copper lap	Tin lap
Wet	20	24	22	....
Dry	8.6	10.3	11.3	18.6

103 It may be of interest to know the rate of cutting in linear measure. With the size of specimen used, the removal of 39 miligrams represented a length of 0.001 in. With a pressure of 15 lb. per sq. in., the average of the best results was just about 22 mg. for 100 rev. of the machine. The length of path traversed by the specimen was 36 in., or 3 feet., per rev. Hence, the specimen moved over the lap a distance of 300 ft. to have ground from its surface 0.00056 in., or 0.00019 in. for 100 ft. of travel over the lap surface.

104 With dry lapping on the tin lap, the best result was 18.6 mg. for 100 rev., which gives 0.00016 in. per 100 ft. of travel. This is with a pressure of 15 lb. per sq. in. on the specimen, and, of course, with a higher pressure a greater amount would be ground off.

CONCLUSIONS

105 In order to present the matter in a more usable form, the main facts, as developed by the investigation and deductions therefrom, are here again set forth:

a The initial rate of cutting is not greatly different for the different abrasives.

b Carborundum maintains its rate better than either of the others, alundum next, and emery the least.

c Carborundum wears the lap about twice as fast, and alundum 1¼ times as fast as emery.

d There is no advantage in using an abrasive coarser than No. 150.

e The rate of cutting is practically proportional to the pressure.

f The wear of the laps is in the following proportions:

Cast iron 1.00 Steel 1.27 Copper 2.62

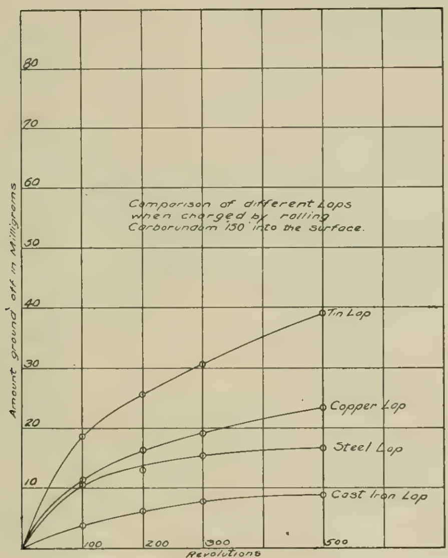


FIG. 74 COMPARISON OF DIFFERENT LAPS CHARGED WITH CARBORUNDUM, No. 150

g This wear is inversely proportional to the hardness by the Brinnel test.

h In general, copper and steel cut faster than cast iron, but where permanence of form is a consideration, cast iron is the superior metal.

i Gasoline and kerosene are the best lubricants to use with cast iron lap; kerosene, on account of its non-evaporative qualities, being first choice.

j Machine and lard oil are the best lubricants to use with copper or steel lap. They are least effective on the cast lap.

k For all laps and all abrasives (of those tested), the cutting is faster with lard oil than with machine oil.

l Alcohol shows no particular merit for the work.

m Turpentine does fairly good work with carborundum, but in general is not as good as kerosene or gasoline.

n Soda water compares favorably with other lubricants. Taken as a whole, it is slightly better than alcohol and turpentine.

o Wet lapping is from 1.2 to 6 times as fast as dry lapping, depending on material of the lap and manner of charging.

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APPENDIX

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The Ohio Water Problem

BY

C. E. SHERMAN, C. E.

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The Ohio Water Problem

By

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Professor of Civil Engineering
The Ohio State University

Maps 1-3 in pocket at end of vol.

1915

FOREWORD

This bulletin is directly the result of two lectures, one given in the Engineering and one in the University lecture course at Ohio State University in January 1913 and January 1914 respectively. The subject of the first was River and Harvor Improvements, and of the second The Ohio Water Problem. Because of reference to local flood protection projects, the city engineer of Columbus, Mr. Henry Maetzel, requested that the substance of the two lectures be published.

The paper is indirectly the result of some observations made during leave of absence from the University in 1912, when the writer inspected a number of waterways from Panama to the Soo. Because of the need of light on the question of disposing of Ohio canals, the subject of transportation on water has received somewhat extended consideration, but altogether too brief as it is. However, it is believed that the essential facts and the correct method of solving this state problem, have been pointed out.

Attention is called to the maps in the text and especially to those in pocket at the rear. They were carefully drawn from best data available by W. D. Turnbull, Assistant Professor of Engineering Drawing at the University. Likewise the material presented in the appendixes is perhaps of more value than much of that in the body of the text.

For brevity the map of Ohio in pocket showing streams, watersheds, etc. is referred to in the text as "water map" of the State, and is marked Map No. 1. The map showing bridge damage thruout Ohio by the flood of 1913, was kindly furnished by J. R. Marker, formerly State Highway Commissioner, and is marked Map No. 4. The Summit-level Project is shown on Map No. 2, and Transportation Routes of the World on Map No. 3, in pocket.

While technical language has been avoided, as far as consistent with clearness, in order to interest the general public, our legislators and state officials, it is hoped the material presented will be of direct interest to the engineering profession.

The writer had in mind originally, treating of all six main streams in Ohio, but the interruptions incident to discharging college duties, directing the State Topographic Survey, and other professional engagements, have delayed even the present brief treatment beyond expectation.

Inadequate as the following paper is, the writer hopes it will materially help Ohioans to lay aside short-sightedness and look fifty years or more into the future in developing an enlightened administration of one of our important natural resources—our surface waters.

October 14, 1915.

CONTENTS

CHAPTER I

PRELIMINARY CONSIDERATIONS

Ever since his connexion with the United States Survey of the three barge canal routes across Ohio, made by a board of Army Engineers in 1895,* the writer has taken a deep interest in the waters of his native State and the problems related thereto. He has for the last decade or more followed closely the administration of our miserable canals, and the legislative debates relating to their abandonment; has acted as consulting engineer on portions of the canals; reported as engineer on private water power projects on various streams in the State; advised in the matter of flood protection at towns radically different in situation; and since May 1902, has directed the Ohio Topographic Survey† as representative of the various governors. This experience, especially that on the Topographic Survey, has brought a knowledge of conditions and possibilities over the State not generally known, some of which it was thought well to set forth.

Above all, the writer is convinced that the true nature of our greatest water problem—The Ohio Water Problem—that of wisely administering our streams, is but little understood, and he began in spare time, some years ago, to collect data for making an exposition of the subject. It was surmised then that the problem consisted of about fifty per cent navigation, twenty per cent water power development, twenty per cent flood protection with the remaining percentage of benefits made up of sanitation, municipal and industrial water supplies, and miscellaneous uses.

Then came the great floods of March, 1913, modifying the above perspective, and filling the public mind with but one idea concerning our streams—how to guard against their devasting floods. Flood protection plans were prepared in many places, some of which came near to being put into operation, that would have resulted in severe economic loss to the communities involved, and thereby in loss to the State at large. To those who were able to take a sober view of the situation, the panic produced and the strange remedies brought forth by the flood seemed truly remarkable. Even after excitement subsided, plans were prepared, which exhibited such a limited view of the situation, that it confirms the conviction that our surface water problems are sadly confused in the public mind.

*The term "Army Engineers" will be used for brevity to designate the officers of the corps of engineers of the United States Army. The Survey referred to was made under the authority of Congress by a board of three such officers, of which, Captain, now General H. M. Chittenden was executive officer. Their report was published in 1896 as House Document 278, 54th Congress, 1st Session. It will be referred to hereafter as the Chittenden Survey or Report.

†What we have here for brevity called the Ohio Topographic Survey is made by the United States Geological Survey in cooperation with Ohio. It is referred to at more length on page 117.

The truth is that our streams should be treated not only for protection against floods which may occur at rare intervals, but they should at the same time be treated for the benefits to be derived from them during the 50 or 100 years intervening between such floods. These collateral advantages may in the long run greatly outweigh the one desideratum of protection against extraordinary floods. Our streams should be treated for positive benefits, rather than from the negative standpoint of guarding against damage from them.

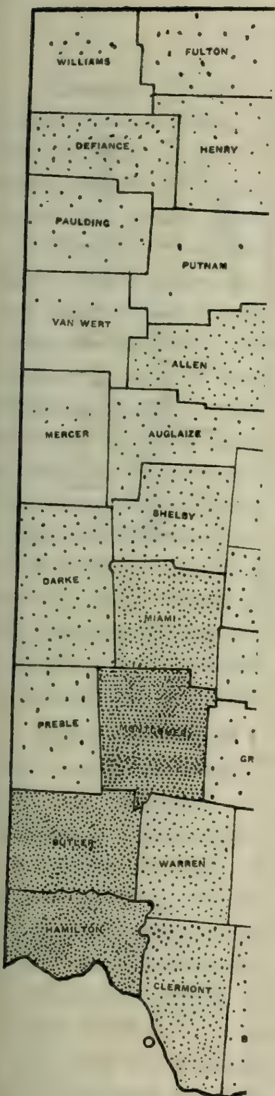
The attitude of mind of the public on sudden losses as contrasted with slow and insidious ones, is remarkable. It is well to recall that we daily endure insidious calamities which greatly exceed in the long run the worst flood damage. Fire losses from poor construction; waste due to preventable human disease; tresspassers killed on railroads; losses from plant and animal diseases; crop shortage from unintelligent farming, any one of these losses thru long periods amounts to more than flood damage, to say nothing of losses from widespread private extravagance, and from industrial and political wastes.

We shall yet have more or less sudden calamities of man's own making, such as wars, riots, strikes, private extravagance, and public waste of our natural resources; and we shall yet have calamities of nature's own making such as floods, tornadoes, drouths, frosts, and epidemic diseases of plants, animals, and possibly of human beings. Against these all we shall do our best to provide, but we should not forget that in providing against the occasional disaster, we should stop insidious waste and make the most of the forces and materials with which nature has endowed us. Among these are our waters, which we proceed to consider.

Stream Regulation

The proper treatment of a stream should take into account, (1) mitigation of its floods, (2) its navigation possibilities, (3) its water power economically developable, (4) its possible sanitary benefits in the way of supplying cities plentifully with potable water and of diluting their wastes, (5) the furnishing of water for industrial purposes and (6) the stream's possibilities for other purposes not inconsistent with the foregoing uses.

So much has been written on the subject of conservation that is general and impracticable, that one almost wishes to avoid the term. Many remedies for stream regulation are proposed and thoughtlessly touted as being of universal application. The truth is that every stream is practically a law unto itself, and every conservation project should be studied by itself, yet studied in the light of all the benefits it may economically secure. We will attempt to lay down fundamental principles under each of the above topics (not necessarily in the exact order above given), and then proceed with an application to a specific example, the Scioto-Sandusky Conservancy district in the region of central Ohio.



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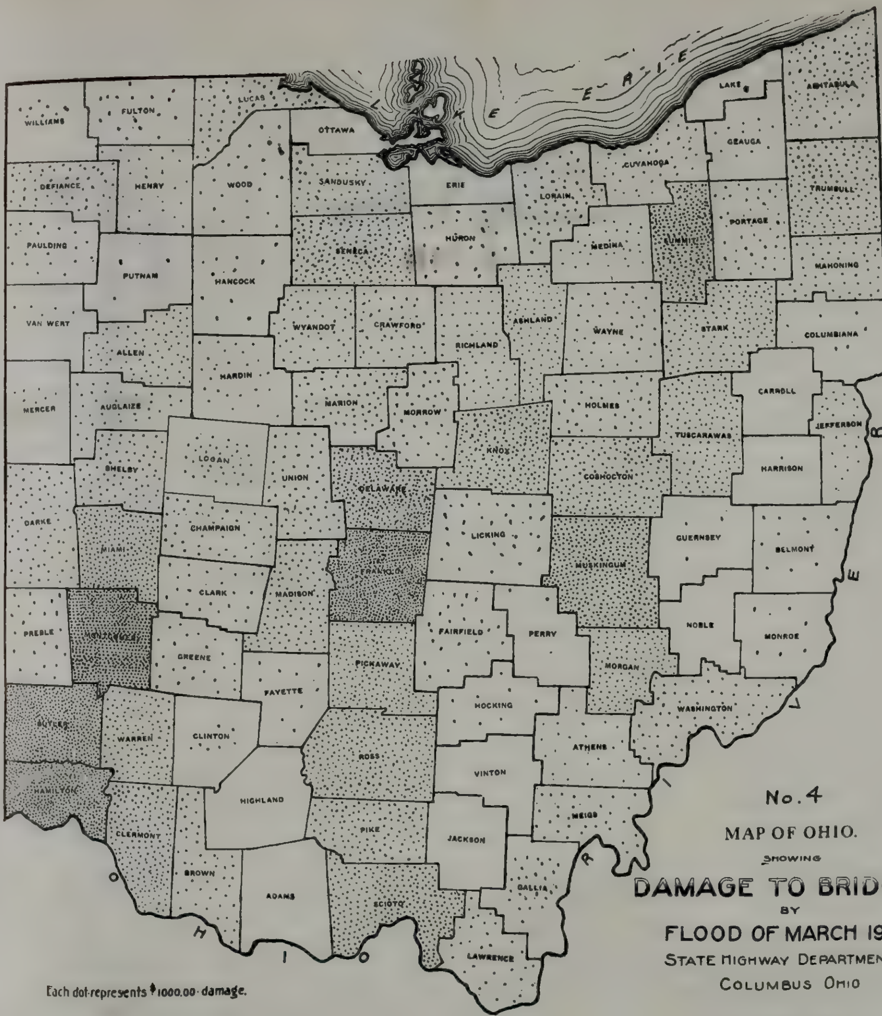


Each dot represents $1000.00 damage.

No. 4

MAP OF OHIO.

SHOWING

DAMAGE TO BRIDGES

BY

FLOOD OF MARCH 1913

STATE HIGHWAY DEPARTMENT

COLUMBUS OHIO

JAMES R. MARKER.
State Highway Commissioner

CHAPTER II

FLOODS

Causes. Flood damage has resulted from at least six causes, (1) excessive precipitation, (2) ice gorges, (3) constriction of channels or of natural flood plains, (4) breaking of dams (bursting reservoirs), (5) high winds, (6) earthquakes. To these causes some would add (7) deforestation, and others would add (8) the tiling and drainage of land.

The fifth and sixth causes do not affect rivers, but the Galveston floods of September, 1900, and of August, 1915, were caused by high winds, and 'tidal' waves due to earthquakes have overwhelmed many sea-coast towns in the past. Deforestation and the drainage of land may effect ordinary floods and ordinary stages of rivers, but we are here chiefly concerned with extraordinary floods, and will refer to forestation and the drainage of lands briefly on page 31. Ice gorges are the chief cause of floods in those north-flowing streams, of which good examples are the Red River of the North, the McKenzie, and others in high latitudes. Ice gorges are rarely effective south of central Ohio. Breaking dams, as a cause of floods, should be eliminated by employing competent engineering talent in their design and construction. That structures fail, is no argument against the use of dams. Such reasoning would also exclude the use of bridges and buildings. The U. S. Reclamation Service is now using dams over 300 feet high.

Rains and Flood Flow. Excessive precipitation far overshadows all other causes of floods in our rivers. Given an excessive precipitation, many factors modify its effect in producing destructive floods. It is necessary to examine these briefly in order to intelligently measure the value of protecting devices. These factors are chiefly, (1) the hydrologic condition of the basin, (2) the relief of the ground, (3) the shape and hydrography of the drainage area, (4) the extent of the area covered by the storm, (5) position of storm area with regard to the drainage basin underneath, (6) duration of storm, (7) intensity, or rate of rainfall. We will consider these in order.

(1) By the *hydrologic condition* is meant the state of saturation of the soil in the basin, or, its capacity for absorbing moisture. This is largely affected by its state of cultivation if the basin is covered with soil. Thus dry plowed land may have a greater capacity for absorbing rainfall, and thereby preventing it from running off as surface water, than a forest cover; it depends on the circumstances. A bare rock surface would have no deterrent effect on surface runoff, and in this respect would correspond to saturated soil. The storm of October, 1910, fell on dry ground and did

little damage, altho that rainfall was greater than the precipitation which caused the greatest recorded Ohio River flood, that of February, 1884. The latter storm fell on ground already saturated, and covered at places with snow. The rain and melted snow ran off together unimpeded. For this reason--that the ground is usually saturated or frozen--rainstorms are more dangerous in late winter and early spring than at other seasons. Contrary to general impression, our monthly rainfall is usually heaviest in summer months.

(2) By *relief* is meant the ups and downs, the hills and hollows, the elevations and depressions of the ground. The relief of the ground upon which the excessive rain falls also affects the flood hights in different ways. Thus from the very steep hillsides of southeastern Ohio the rainfall escapes with a rush, causing sudden high flood crests which quickly subside. A mountain torrent after a cloudburst is an extreme example of this. On the other hand, from the extremely flat area in northwestern Ohio, the water runs off much more slowly and at lower crest. The St. John River in Florida is an extreme illustration of this class of streams.

(3) The *shape of the polygon* traced by a stream's watershed and its hydrography (that is the relative position of the streams within the watershed) affect the hight to which its flood waters are liable to rise. Thus a long slender drainage area, like that of the Olentangy or of the lower Scioto, ordinarily does not offer opportunity for such crest hights, as a more rounded basin, like that of the Miami at Dayton, or the Muskingum at Coshocton, where several large tributaries entering the main stream at one place may heap their simultaneous discharges one on the other. In a long slender basin with branches joining the main river at intervals, downstream from each other, the water in one branch may run out and downstream before the discharges from the upper tributaries have arrived.

(4) The *extent of the area* which a severe rainstorm may cover is independent of the mean annual rainfall shown in Figure 1. Nor is it affected by such hills as we have in Ohio. The surface features of our State, such as its forests or its hills do not extend high enough up in the air (as do the Cascade Mountains, for example, thus modifying storms from the Pacific), nor do they produce other effects far reaching enough to modify big wind and rainstorm tracks across the country. Weather bureau records of more than 1000 storm tracks show that Ohio lies directly in the path of nearly all cyclonic* storms proceeding from the Mississippi Valley out over New England and the St. Lawrence into the Atlantic. This is the general direction of all widespread (cyclonic) rain-

*Cyclonic storms which are widespread must be distinguished from tornadoes with which they are popularly confused; and must be distinguished from the summer thunder storms which are usually so local and often intense, as illustrated in Figures 5 and 8. (See any good work on Meteorology.)

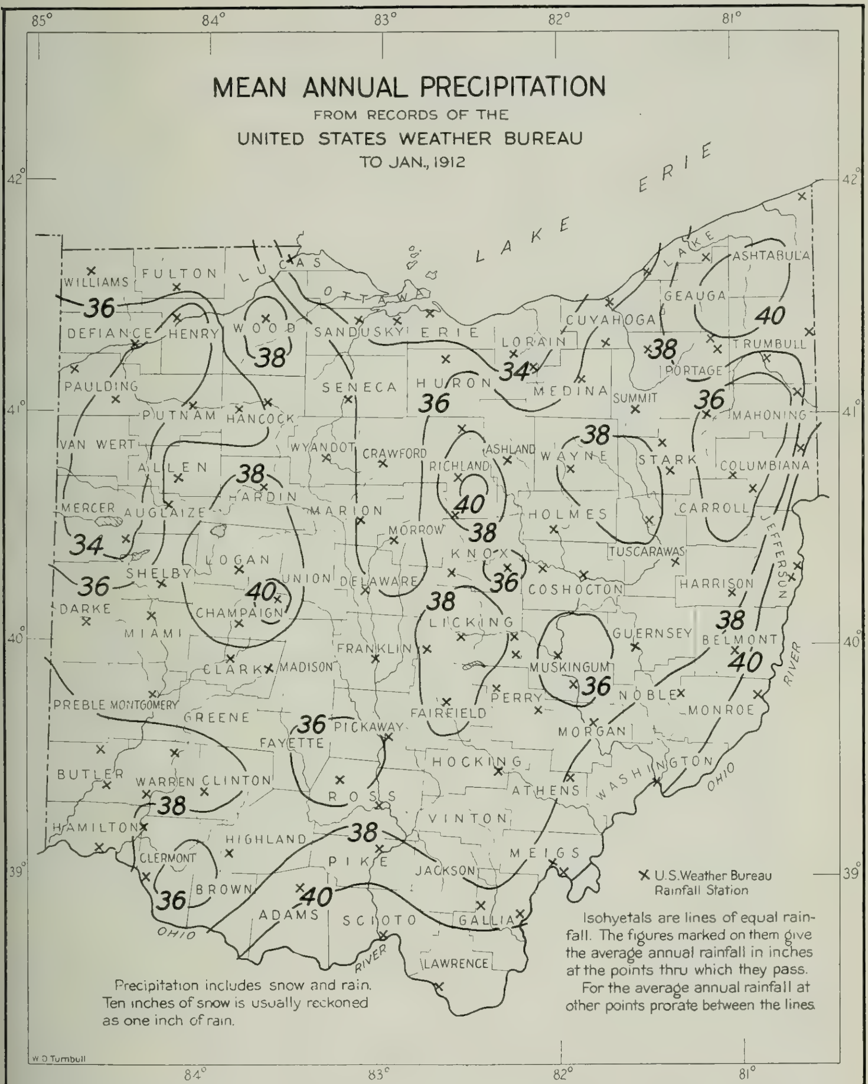


Figure 1

Ohio has in all 110 or more U. S. Weather Bureau rainfall stations well scattered over the State as shown above. This is an average of one station to each 375 square miles. (The 88 counties in Ohio each average 469 square miles in area.) The longest record is that at Marietta, dating back to 1817.

storms in Ohio without exception. This becomes apparent when the weather records are extensively examined. The charts here presented of the greatest rainstorms that have happened in Ohio in recent years, suggest the general truth of the above statements, and of the statement made below, that the position of storm areas in Ohio is independent of our surface features.

The size of the area covered by an intense storm has of course an important relation to the flood it produces. If the whole basin is covered the effect is most severe, but of course, the larger the basin the less liable it is to be completely covered by such a storm. Figures 2, 3, 4, and 5 show the areas covered by the four greatest storms we have had since our weather records have been carefully kept. The great storm of March, 1913, so far as we know, is the greatest rainstorm that the Mississippi Valley has yet experienced in the amount of water that fell and the wide area covered. This heavy storm extended from Illinois to New England, its intensest portion covering Ohio as shown in Figure 4. Those who wish details are referred to Bulletin Z of the U. S. Weather Bureau. The storm was really two cyclonic storms following one another so closely as to be practically one.

(5) Likewise the *position of a storm area*—both of general cyclonic storms and summer thunder storms—with reference to the location of the streams underneath it is independent of the mean annual rainfall and the surface features above mentioned, and it greatly affects the resulting flood hights. Thus the storm of March, 1907, shown in Figure 2, falling on the upper reaches of the Hocking, raised the ensuing flood at Athens to a hight three feet greater than the flood of March, 1913. The storm of October, 1910, Figure 3, fell on lower river reaches where the channel capacities are large, as did also the storm of July, 1913, (see Figure 5), which fell in the most favorable place for *not* producing a disastrous flood. It fell over the central part of the Muskingum basin, where the river channels are ample. Had this storm fallen on the 420 square miles of Olentangy River basin above Delaware, the disaster to that city would have exceeded the disaster of March, 1913.

The storm of March, 1913, as shown in Figure 4, was remarkable, not only for the large area it covered, its duration, and intensity, but it was also most effectively placed over the drainage basins beneath it for producing calamitous floods thruout the State. It had also the remarkable peculiarity of following southbound floods downstream to an extent explained in the bulletins of the United States Weather Bureau by Prof. J. Warren Smith.

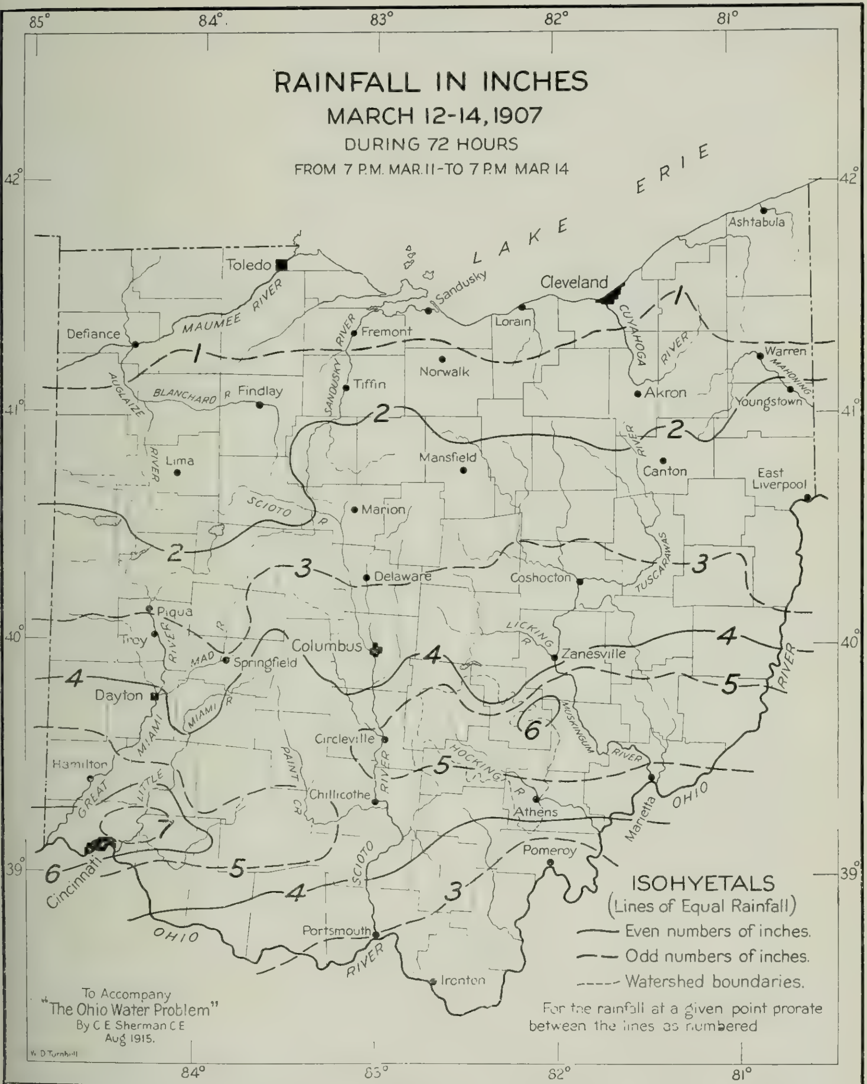


Figure 2

The above rain fell on ground saturated by rainfall over the State on March 10, preceding. The heaviest fall occurred near Cincinnati where the channels were ample. Most damage was done on the Hocking River.

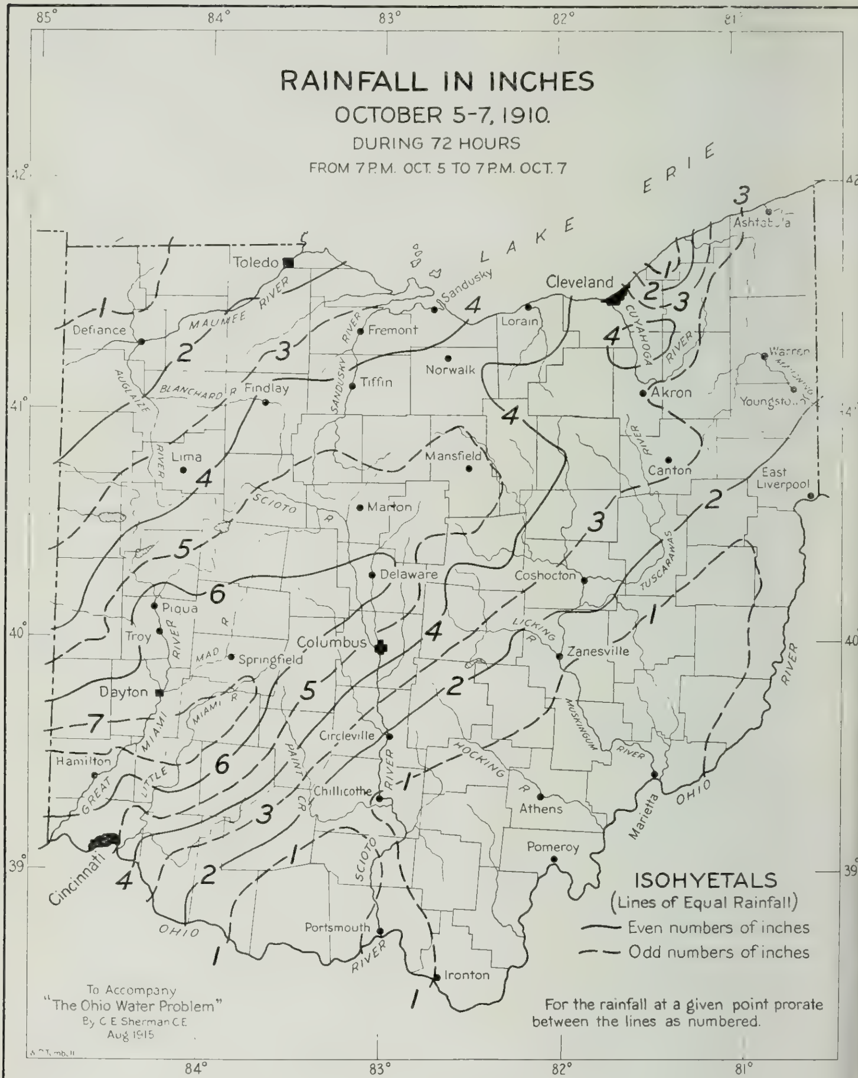


Figure 3

This storm was heaviest in southern Indiana and Illinois. It fell on dry ground *and on lower river reaches* where channels were large, and hence did little damage.

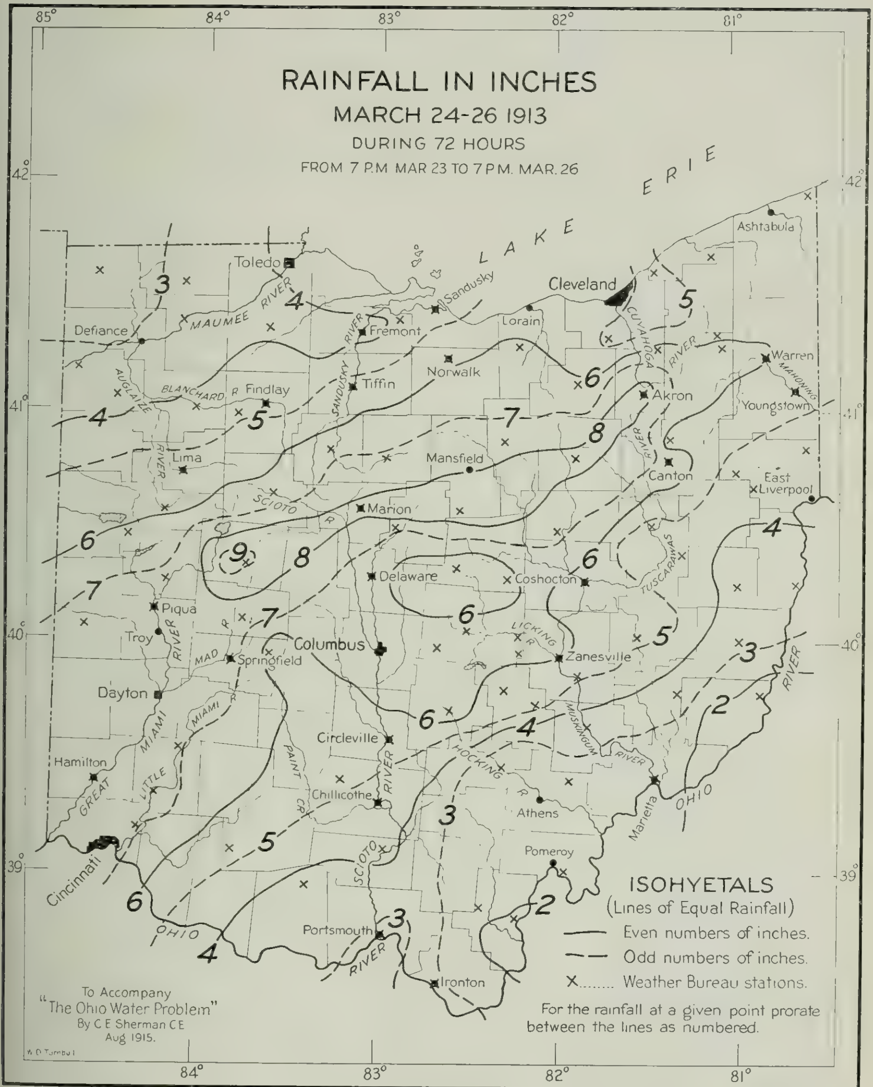


Figure 4

The rainfall pictured above was preceded by precipitation over nearly the whole State on Easter Sunday, March 23, sufficient to saturate the ground before the above heavy rain fell.

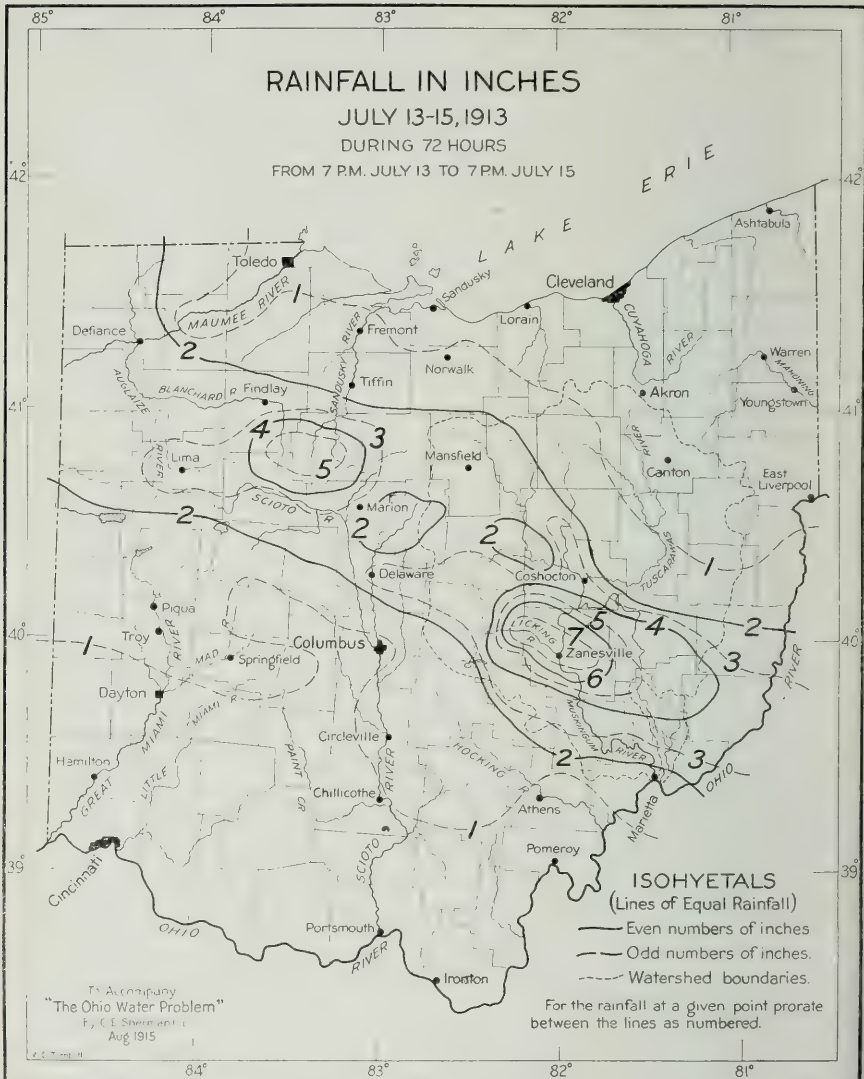


Figure 5

Practically all the heaviest precipitation shown above at Zanesville and vicinity *fell within 10 hours* during the night of Sunday, July 13. See Table II in text.

(6) The *duration* of a storm of given intensity, covering a given area, has an effect not generally understood by the public. Suppose on a basin like that of the Scioto above Columbus, in which it is 75 or 80 miles by river from the City to headwaters, it rained steadily at the rate of 3 inches daily for two days on ground already saturated before the storm began. If all the water traveled downstream at the average rate of nearly two miles per hour (and the average speed is about that in this basin from headwaters to Columbus) the river would reach crest at Columbus at about the end of the second day.

During the first twenty-four hours, all water falling at the outset in the basin within 40 miles of town would pass by the City before the upper waters came down. At the end of the second day all waters, which fell the first day upon farthest headwaters, would be heaped on those still falling upon and escaping from the 40 mile district the second day, thus creating maximum high water at the City. The river would reach crest successively at about 40 and 80 miles downstream from headwaters, at the end of the first and second days respectively, but these crests would be greater in volume, and ordinarily greater as compared with channel capacity, as they proceeded downstream. For example, if this rain continued three days over the entire basin it would crest unprecedentedly at Chillicothe (40 or 50 miles downstream from Columbus) on the third day.

The violence of the flood, in the above Columbus example, can be readily computed if we know the area of the basin. Suppose the area of the basin above Columbus to be 1000 square miles, then 1000 sq. mi. times 640 acres, times 43,560 sq. ft. in an acre, times 3 inches reduced to feet divided by the number of seconds in which the 3-inch fall occurs, gives the maximum flood-flow in cubic feet per second, that is the discharge in second-feet as it is usually abbreviated. Calculated in this way the flow at crest is found to be 80,667 second-feet, or, about 80 second-feet per square mile of drainage area.*

This is not far from what actually happened at Columbus on the Scioto just above its junction with the Olentangy, at noon on Tuesday, March 25, 1913, after the ground had been previously soaked by the rain

*One inch of rainfall in a month on a square mile is nearly equal (about 10% less) to a flow of one second-foot for a month. This furnishes a readier method than the above for reckoning floods. Example: a rate of 3 inches a day is 90 times a rate of 1 inch per month. Subtracting 10% from 90 we get 81 second-feet per square mile of basin, which is closely what we calculated by the longer method above

For small areas, such as city sewer districts, farms or small gullies, use the following simple method: One inch of rain on an acre is equivalent to a flow or runoff of one second-foot for an hour. Since an acre is about 209 feet square, if one will think in acres when looking at a small area, he may readily compute mentally the runoff of an assumed storm.

The foregoing two simple rules are not exact, but they are within one per cent of the truth, which is closer than the data usually will warrant. *They are for storms falling on saturated ground.*

of March 23. Details varied from the above assumptions; for example the drainage area is more nearly 1050 sq. mi., and it did not rain uniformly over the whole basin, during the period of the storm.

It does not rain uniformly over any basin during the period of a storm. However, the smaller the basin, the more nearly the rainfall over it may approach uniformity. Likewise, the smaller the basin the more intense may be the storm covering it. So that small drainage areas are apt to experience storms and resulting floods relatively severer than those on larger river basins. For example, taking the Mississippi basin as a whole it might be raining hard in Ohio and not at all in Kansas. On the other hand a cloudburst might completely cover a small gully, as happened at the Columbus Fishing Club's stock pond in 1906, or as happened in Guernsey County, July 16, 1914. (See Figure 8.)

The above general principles are exhibited in the accompanying diagram, Figure 6, and are further exemplified in the following table of the greatest floods yet recorded at the points listed:

Table 1

Name of Stream	*Area of drainage basin square miles*	*Max. discharge in sec.-feet per square mile*
Olentangy at Delaware	422	110
Scioto at Columbus dam	1,037	80
Ohio River at Cairo	205,750	7
Missouri at its mouth	530,810	2

Some of the figures in the above table have been plotted in Figure 6 for comparison. The reader may readily use this diagram in computing interesting flood possibilities for cities other than Columbus, if the areas of the drainage basins above those cities are available. (For a list of Ohio drainage basin areas, see Appendix B.) It can readily be seen by so calculating, that other places not more favorably situated, and hitherto saved from floods, have their experience yet to get. We shall continue to hear of record floods here and there at various towns thruout the country.

Let us calculate one more example just to emphasize the importance of duration. Suppose it rained one third of an inch daily during the month of March uniformly over the whole Ohio River basin. No one on our small streams would notice floods in their valleys. No one in Dayton, Columbus or in other towns on the Miami, Scioto or Muskingum would experience inconvenience from floods. At Cincinnati, the Ohio would be in flood, but not at as great a hight as has happened in the past; but at the mouth of the river, Cairo would have a hight exceeding anything it has yet experienced in recorded history. The maximum flow thru there would be about 1,800,000 second-feet, which compare with line 3 in the foregoing table.

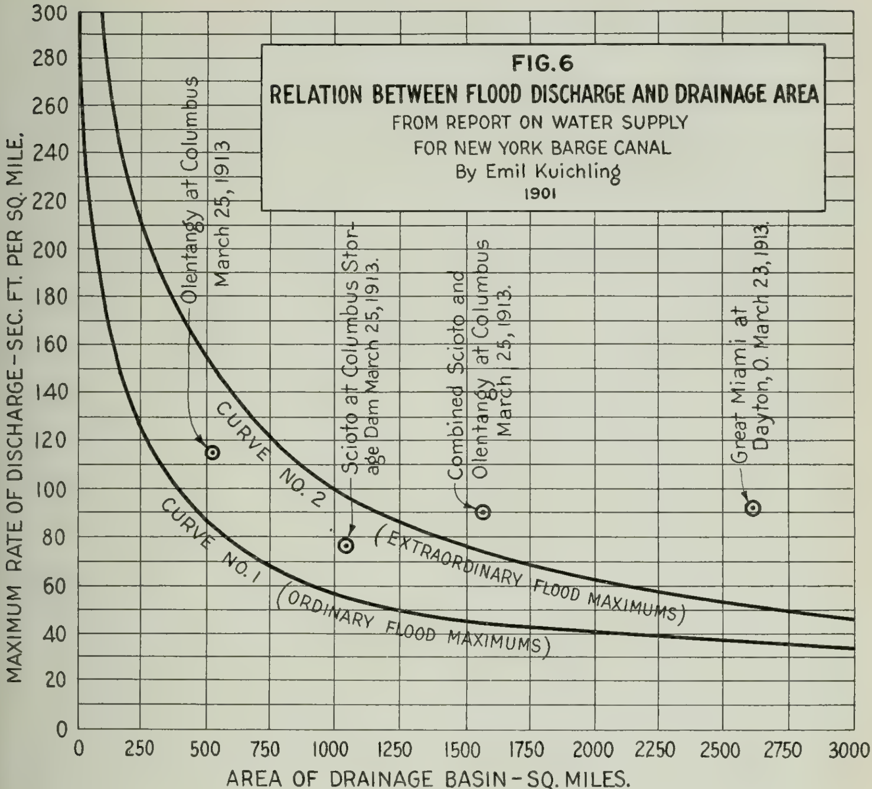


FIG. 6
RELATION BETWEEN FLOOD DISCHARGE AND DRAINAGE AREA
FROM REPORT ON WATER SUPPLY
FOR NEW YORK BARGE CANAL
By Emil Kuichling
1901

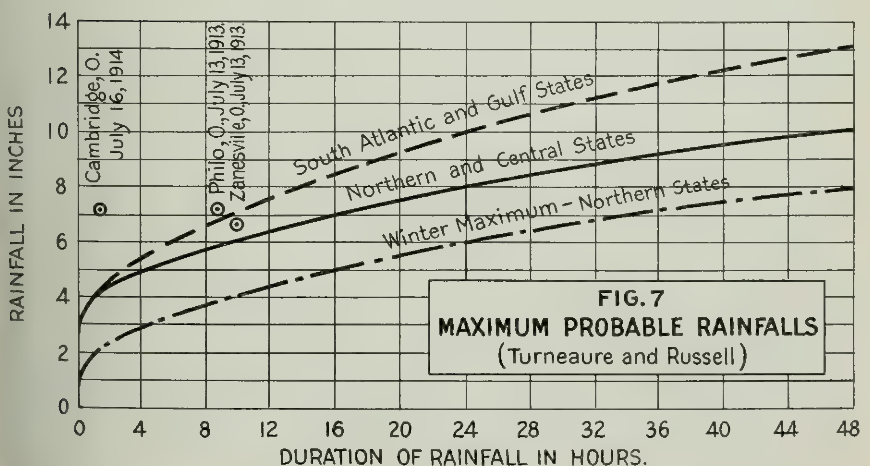


FIG. 7
MAXIMUM PROBABLE RAINFALLS
(Turneaure and Russell)

This last example will help make clear the important effect of duration of rainfall of given intensity, or averaging a given intensity over an entire watershed. If such a storm (completely covering a given basin) lasts long enough, every other factor affecting flood hights gives way. It matters not whether the surface of the basin be hilly or flat, whether its area is wooded or is all bare rock, whether tributaries join the main stream at intervals or all come in together, these factors all vanish and the maximum flood discharge becomes proportional to the area of the basin and intensity of rainfall. This is practically what happened on the main Ohio streams at points 75 or 100 miles down from headwaters in March, 1913. The maximum discharge thru Columbus, from 1600 sq. mi. of basin above it, was about 140,000 second-feet. The flood discharge thru Dayton at crest was about 240,000 second-feet from a drainage area of 2600 sq. mi., which is nearly in proportion to the Columbus flood, allowance being made for slight difference in average intensity in the basins; and while accurate data is not available for the Muskingum, rough estimates show that the 1913 flood closely followed the general law there, when the difference in average intensity is allowed for.

(7) By the *intensity* of a rainstorm is meant the rate of precipitation. As stated at the outset we are dealing only with heavy rainfalls in this paper. Other things being equal the flood will vary directly with the intensity. Thus, if instead of raining 3 inches daily for two days on the Scioto basin above Columbus, suppose it rained 6 inches daily for two days over the whole basin, the resulting maximum flood discharge at the storage dam (6 miles above the mouth of the Olentangy) would be 160,000 second-feet, instead of the 80,000 second-feet which we have already calculated.*

The maximum intensity of the rainfall which may be expected at a given point in this region is shown in Figure 7. This curve, taken from Turneaure and Russell's Public Water Supplies, is simply a summary, in graphical form, of the experience at rainfall stations in the North Central States. It gives no idea of how much area a rainfall of given intensity may cover—this, as we have just seen, is a most important factor.† The curve simply summarizes experience up to the time it was drawn.

There is no reason why it may not be exceeded at any given station in the future. In fact, in July of last year, a rain fell near Cambridge, Ohio, which greatly exceeded in intensity any experience summarized in the curve. The area of this storm is shown in Figure 8, and it just happened

*Mr. Samuel Gray, in designing the storage dam, made the spillway large enough to discharge 160,000 second-feet. The spillway notch (discharging weir) is 500 feet long by 22 feet deep. This notch was filled up to a depth of 12.8 feet when the 1913 flood discharged 80,000 second-feet thru it.

†The writer attempted to prepare a diagram showing relation between maximum probable intensity and area covered by a storm, but found the data too incomplete to be satisfactory.

to center over a rainfall station, where they were ready to measure the precipitation accurately, (an unusual situation). Doubtless such rains have fallen in the past at places where they were not measured and recorded.

The storm of July, 1913, shown in Figure 5, was remarkably intense considering the area it covered. The returns fom the weather bureau stations in Muskingum County and vicinity show the precipitation to have been as given below. Since rainfall measurements are generally made at 24-hour intervals, not all the stations below reported the intense portion separately.

Table II

Station	*Inches of rain*
Toboso	7.4 up to 6.30 A. M. of July 14
Gratiot	3.98 in 8 hrs. during Sunday night, July 13
Crooksville	3.56 in 6½ hrs. during Sunday night, July 13
Coshocton	3.15 in 24 hrs. up to 7 A. M. of the 14th
Zanesville	6.7 in 10 hrs. during Sunday night
*Philo (hill)	6.48 in 8 hrs. and 42 min. Sunday night
*Philo (valley)	7.17 in 8 hrs. and 42 min. Sunday night
McConnelsville	3.24 in 12 hrs. during Sunday night
Cambridge	4.46 in 12 hrs. during Sunday night
Summerfield	4.51 in 24 hrs. nearly all during Sunday night
Clarington	3.50 in 12 hrs. during Sunday night

If the rainfalls just given are plotted on the diagram in Figure 7, some of them will be found to be very intense. The rainfall of July, 1914, given in Figure 8, we have so plotted for comparison. Should a heavy rain occur in late winter or early spring, on ground already covered with snow, the effect is, of course, the sum of the two precipitations ,(ten inches of fresh snow is usually counted equivalent to one inch of rain). The possibility of this happening at some future time must be recognized.

In semi-arid regions the rainfall is sometimes exceedingly intense. The most remarkable rainfall and ensuing flood in North America, that the writer has heard of, occurred in August, 1909, at Monterey, Mexico. as reported in the Engineering News of September 23, of that year. From August 9 to 11, within 42 hours, 13.38 inches of rain fell; and from the 25th to the 29th *of the same month* within a period of 98 hours, 21.61 inches fell. The annual rainfall at this station for 21 years past had averaged 19.86 inches (or about half the annual rainfall in Ohio), so that during the second storm there, lasting about 4 days, more water fell than usually falls in a year.

*Philo is downstream 9 miles from Zanesville. Two official observers made returns from this place.

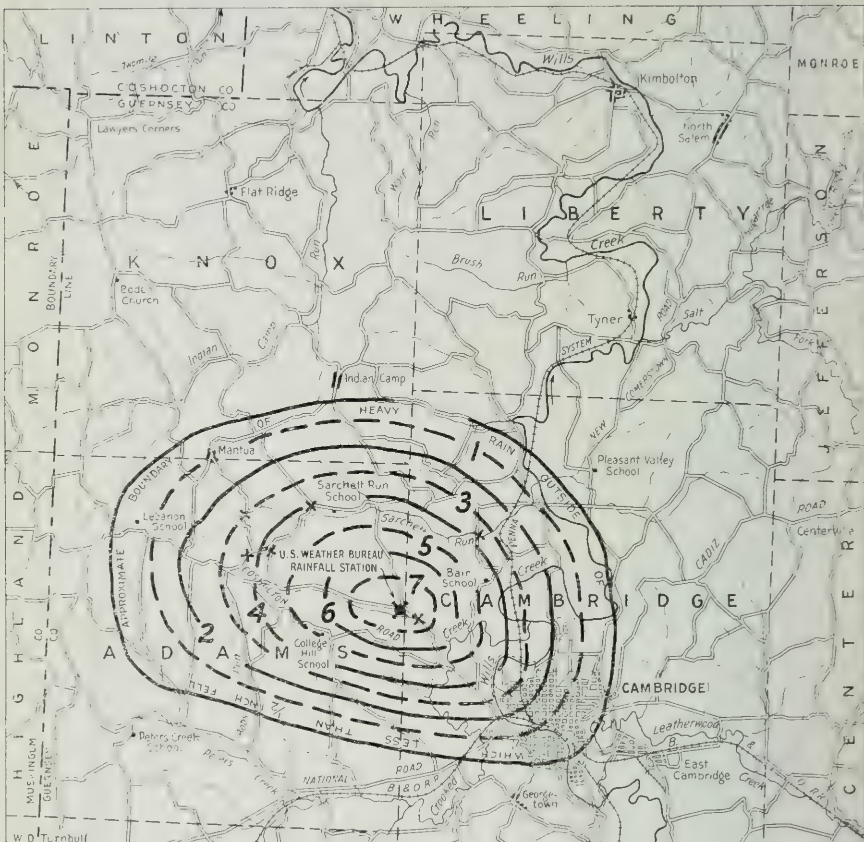


FIG. 8

NINETY MINUTE RAINSTORM NEAR CAMBRIDGE, O., JULY 16, 1914

7.09 INCHES FELL AT THE U.S. RAINFALL STATION

SCALE OF MILES

0 1 2 3 4 5

Figure 8

The outside boundary of this storm was traced upon the Cambridge quadrangle of the Topographic Survey by the county surveyor of Guernsey County shortly after the storm. It has been assumed to be ½ inch, and the isohyetals have been proportioned between it and the U. S. station.

The Monterey storm is interesting as showing what could possibly happen in Ohio, altho such is not probable. The contingency is probably as remote as an earthquake, but it shows that we cannot be absolutely safe from nature's forces. While the rainfall at other points on the basin was not measured, it is known that the resulting flood at Monterey was about 270,000 second-feet at crest, from a drainage basin of 544 square miles above the city, or almost exactly 500 second-feet per square mile of basin. Compare this with the maximum discharge of the Olentangy at Columbus in March, 1913, when nearly 60,000 second-feet was discharged from 520 square miles of basin, or about 110 second-feet per square mile of drainage area.

Remarks on Rainfall Charts. Only the intense or flood causing portions of the great rainstorms pictured in Figures 2, 3, 4 and 5 are shown. For further details the reports of the U. S. Weather Bureau should be consulted.

The rainfalls have all been plotted for the intensest 3-day period, for the purpose of general comparison. The details of distribution, however, varied greatly as is shown. Likewise the intensities varied greatly as is suggested in Table II. The great bulk of the storm shown in Figure 5, fell during the night of Sunday, July 13, 1913, as shown in the table. This rainfall would be credited to July 14, 1913, in the U. S. Weather Bureau bulletins, because their 24-hour records begin usually at 7 P. M.

Altho Ohio is as well supplied with rainfall measuring stations (see Figure I) as any of the North Central States, it is not possible to represent the actual rainfall exactly. The rainfall stations would have to be infinite in number to do this. Figure 8 will seem to be crudely drawn because only one rainfall station is plotted. It is, however, more accurate probably than Figures 2, 3, 4 and 5. The large scale to which Figure 8 is drawn makes it seem crude. Figures 2, 3, 4 and 5 have, however, been drawn upon maps to a large scale with mathematical accuracy as far as the data were available, and these maps photographed down to the size of the figures herewith presented.

On the large scale originals, planimeter computations of the volumes of precipitations were made and the results are given in Table III. As a check in each case the total partial areas were added to see if they equaled 41,240 square miles which is the area of the State. The volumes of rainfall are tabulated in acre-feet, which is a unit meaning one foot of rainfall on an acre, or 43,560 cubic feet. If volume of precipitation alone be considered, we see from Table III that the storm of March, 1913, is the greatest. If we say that that the flood producing size of a rainstorm depends upon three factors, namely, the volume of precipitation, divided by the area upon which it falls, and the quotient by the hours of duration,

then the storm falling over Muskingum County and vicinity in July, 1913, is the worst in the State of which we have record.

Future Flood Possibilities. Will such a rain as that of March, 1913, ever occur again in Ohio? It can be safely said that it will not; because, just as no two streams are alike, so, no two rainstorms are exactly alike in all details of precipitation. The rainstorm charts already presented sufficiently suggest this fact, and hundreds of others if similarly plotted will show the same thing. If every stream is a law unto itself with regard to its accompanying conditions, so is every rainstorm a law unto itself with regard to its details of distribution, intensity, and duration; and since the hydrologic condition of a basin may vary in several ways for each storm, the complexity of the problem of dealing with floods becomes at once apparent. It should give pause to the numerous persons who contribute sure cures for floods to the newspapers and magazines.

But, while no two floods are alike in all their details, they may reach the same hight of crest at given points. This crest hight is the crucial feature. Will we ever have crest hights exceeding those of March, 1913? Probably yes; if we take a long enough period of time. At points on smaller streams in Ohio, we have already experienced, within recorded history, flood crests exceeding in hight those of the date just mentioned, and if we go back to glacial times, we have undoubtedly had greater hights on all our main streams.

But it is not economically wise to plan for a geological epoch, and we are unfortunate in not having enough recent experience to compare with the 800 years of recorded experience on the Danube and the 1200 years of flood crest records on the Nile.* Our more or less carefully recorded experience covers only 100 years, and indicates that the 1913 flood hights have not been exceeded in that time on our main Ohio streams, (that is, at points downstream far enough to be past "cloud-burst" effects). The law of probability indicates that they will not be exceeded during the next 100 years. The law of probability does not exclude possibilities, however. It is possible for a big rain to fall on ground heavily covered with snow, and both run off together at greater crest hights, than any we have yet experienced. This possibility, as has already been noted, was taken into account by Samuel Gray in designing the present Columbus storage dam. Should the spillway of that dam discharge the amount he designed it for, and the Olentangy basin be in similar rainfall condition simultaneously—as would almost certainly be the case—the flood discharge thru Columbus at crest would be more than 250,000 second-feet, versus 140,000 second-feet March 25, 1913.

*See Willcocks Egyptian Irrigation, Page 32.

TABLE III
STORM AREAS
Shown in Figures 2, 3, 4 and 5

1	2	3	4	5	6	7	8	9
Inches of Rain	March 1907		October 1910		March 1913		July 1913	
	Sq. Mi.	Acres	Sq. Mi.	Acres	Sq. Mi.	Acres	Sq. Mi.	Acres
9					57 =	36480 *27360		
8½					1607 =	1028480 *728507		
8								
7½	178 =	113920 *71200			6442 =	4122880 *2576800		
7			707 =	452480 *263947			212 =	135680 *79147
6½	531 =	339840 *184080	3008 =	1925120 *1042773	6983 =	4469120 *2420773	254 =	162560 *88053
6	79 =	50560 *25280						
5½	4274 =	2735360 *1253707	4198 =	2686720 *1231413	9539 =	6104960 *2798107	353 =	225920 *103547
5					363 =	232320 *96800	226 =	144640 *60267
4½	5972 =	3822080 *1433280	5170 =	3308800 *1240800	5618 =	3595520 *1348320	1266 =	810240 *303840
4			206 =	131840 *43947				
3½	7585 =	4854400 *1415867	6131 =	3923840 *1144453	5943 =	3803520 *1109360	2762 =	1767680 *515573
3					107 =	68480 *17120		
2½	9397 =	6014080 *1252933	6957 =	4452480 *927600	3874 =	2479360 *516534	6945 =	4444800 *926000
2					527 =	337280 *56213	499 =	319360 *53227
1½	7425 =	4752000 *594000	6682 =	4276480 *534560			10379 =	6642560 *830320
1			1350 =	864000 *72000			87 =	55680 *4640
¾			6761 =	4327040 *270440			10433 =	6677120 *417320
½	5669 =	3628160 *151173					7746 =	4957440 *206560
TOTALS	41110 SQ. MI. 6381520 AC. FT.		41170 SQ. MI. 6771993 AC. FT.		41060 SQ. MI. 11695894 AC. FT.		41162 SQ. MI. 3588494 AC. FT.	

* Indicates Acre Feet

For example: The area covered by 7 inches (or more) in July 1913 from the above table was 212 sq. mi. = 135680 acres, and the total precipitation within this area was 79,147 ac. ft.

Again, there is no reason why a heavy summer shower, such as is shown in Figure 5, may not fall at any place in the State. By transposing this storm upon various portions of the map of Ohio—in pocket at the rear of this paper—possibilities may be seen which cannot be provided against by any expenditure at all within reason. Thus, for example, if that storm be transposed with its axis revolved* upon the Olentangy basin above Delaware, that city would experience a flood much greater than that of March, 1913, and as previously stated relative flood intensity there, was greater than at any other point carefully estimated in the State.

Likewise if the Zanesville storm (Figure 5) be superimposed most effectively upon the area immediately above Hamilton, Ohio, the resulting maximum flood discharge thru that city would equal the maximum flood discharge thru Columbus in March, 1913, even though all the "dry reservoirs" now proposed for the protection of Dayton and the Great Miami Valley—as shown on state watermap in pocket at rear—were constructed and in operation.

Any reader may satisfy himself of the general truth of the foregoing two examples by plotting the heaviest rainfall of Figure 5 on transparent paper to the same scale as Map No. 1 in pocket, and using areas in table III accompanying in connection with the average speeds of run-off which would prevail in the different drainage basins. As an additional example; if the maximum discharge of the Muskingum at Philo (9 miles downstream from Zanesville) due to the rain within the 6-inch isohyetal which fell during 10 or 12 hours Sunday night, July 13, 1913, be considered and an average speed of 3 miles per hour be assumed for the water running down the steep hillsides and channels of that region, all water within the 466 square miles contained within the 6-inch isohyetal (see column 8, Table III) would reach Philo, even by the longest channel route inside the area, within 12 hours.

Then by the short rule given at the bottom of Page 11, the flood discharge would be 466 square miles times (assuming 6 inches average rain over the area during 12 hours equals 360 times a rate of 1-inch per month) 360 equals 167,760 second-feet, less 10%, equals 150,884 second-feet. This would be the flood due to rain inside the 6-inch isohyetal under the assumptions made. Similar computations could be applied to the 5 and 4-inch areas and other modifications and refinements too lengthy to explain here, should be considered in more careful computations.† We can-

*There is no law governing the direction of summer thunder showers, such as those shown in Figures 5 and 8, as there is governing the general direction of great cyclonic storms, such as those shown in Figures 2, 3 and 4.

†The isohyetals are best drawn in black ink on tracing cloth or paper, which when superimposed upon Map No. 1, permits the watersheds to be traced in red and the stream channels traced in blue. The run-off from a given rainfall on a given basin may then be readily studied from this tracing.

not, in any event, compute floods with mathematical precision; but, by making reasonable assumptions upon the rainfall and topographic data furnished, this method yields a check computation on other methods of flood measurements. It is sometimes the only method available. Best of all it affords the easiest method of foreseeing possibilities resulting from assumed rainfalls.

Unfortunately no direct measurement was made of the Philo flood. No direct measurements have been made of any of our great floods. People are all occupied with more strenuous matters during times of maximum floods, and such volumes have to be computed by indirect methods.

The Muskingum flood above mentioned, due to the summer thunder shower of July 13, 1913, however, approximated closely what we have figured it to have been at Philo. The flood wave from this storm took out two temporary bridges at Marietta, all others from Philo to the mouth of the Muskingum, having been washed out by the flood of four months previous.

A portion of the above Muskingum County storm falling on the headwaters of Duck Creek, Sunday night, is reported to have stopped the Pennsylvania Railroad train leaving Marietta at 6:40, Monday morning, at Stanleyville, 9 miles north, barely allowing passengers time to escape to high ground, before finally completely submerging the train. Unfortunately we have no accurate measurement of this remarkable flood. It is to be regretted that we have not more accurate data of any of the great storms and floods that have occured in the State.

Conclusions. We have just indicated what is possible in the way of floods by transposing the Zanesville storm at other places. Similarly the Cambridge storm (Figure 8) might be so transposed. At Columbus, on August 24, 1915, considerable annoyance was experienced from one inch of rain falling in 15 minutes. Suppose 7 inches had fallen on the city in 90 minutes, as happened at the Cambridge observing station. Since such a storm may happen at any point in the State, it is impossible to guard against the local damage it would do if it should fall on a small drainage basin. *We have used Ohio experience in discussing possibilities.* Our experience is not yet complete. Suppose greater storms—approaching the Monterey storms—fell within the State.

The foregoing has been written not to preach calamity, but to make clear the fact, that flood protection plans are not as certain to accomplish positive results as are plans for developing water power, for promoting navigation, for securing potable water, for insuring better manufacturing facilities, and for accomplishing other miscellaneous purposes set forth in later pages. The foregoing is written to correct the popular misunderstanding of stream regulation problems in this State, which is that absolute

flood protection is the one thing to secure. *We can not be absolutely safe from floods if we intend to use the valleys.*

However, greater floods than we have had must be classed with other calamities; such as earthquakes, tornadoes, great drouths, or great freezes. To be absolutely safe from floods we should move out of valleys up onto the hills, but in so doing we might move into the track of a tornado coming later. The great rainstorm of March, 1913, started with a tornado at Omaha. Altho that city lies high enough to escape floods, the wind killed between 90 and 100 people there, which was the same number drowned at both Dayton and Columbus. The property loss also at Omaha paralleled that at Columbus. The property loss at Dayton, however, was greater; because the center of the city occupied the flooded valley, whereas, at Columbus only a comparatively small portion of the residence district stretched across the flood plain.

CHAPTER III

FLOOD PROTECTION PLANS

Really a form of Insurance. Floods may be met by commercial or public insurance, or works may be constructed for mitigating or preventing their damage. Either method is really a form of insurance, and the value of the results to be accomplished, is a measure of the proper price to pay. If the price is otherwise too high, it may be advisable to use a river valley without protecting works, in spite of frequent floods. Such has been the case at many Ohio River towns. The inhabitants of these towns simply retire to higher ground until excessive floods subside, and, so common have such occurrences become, that in March, 1913, only three or four lives were lost along that river in Ohio, as compared with more than 420 lives on streams up-state. The property loss could be met by insurance companies, or, a river town might offer as inducement to prospective industries, for locating within its limits, to make good the flood losses such industries might suffer. However this method of meeting flood damage has not been largely developed. It may yet become established, as is tornado insurance.

Seven Methods. Other methods of mitigating flood damage on a given stream are as follows: (1) increasing the size of the channel, (2) use of levees, (3) increasing the grade or longitudinal slope of stream, (4) diverting a portion of the drainage basin to another outlet, (5) use of detaining or impeding dams (dry reservoirs), (6) impounding or storage reservoirs. To which some would add (7) reforestation or afforestation.

Which of these methods is best? It is like asking a physician which medicine is best, yet there are those who have unhesitatingly recommended one remedy or another as of universal application without inquiring into the symptoms. The truth is that one remedy, or a combination of several or of all, may be applicable to a given stream. It depends on the circumstances. No remedy is of universal application. It would be foolish to attempt to mitigate flood damage on the lower Mississippi by diverting a portion of its waters to other drainage basins. It would be nearly as foolish to try to control those floods by reservoirs or by reforestation. Yet these methods may have value elsewhere. We will consider each of the seven methods listed above.

(1) The section of the *channel may be increased* by widening, deepening or removing obstructions, or by any combination of the three. Usually the first and the last are the only directions in which the size may be

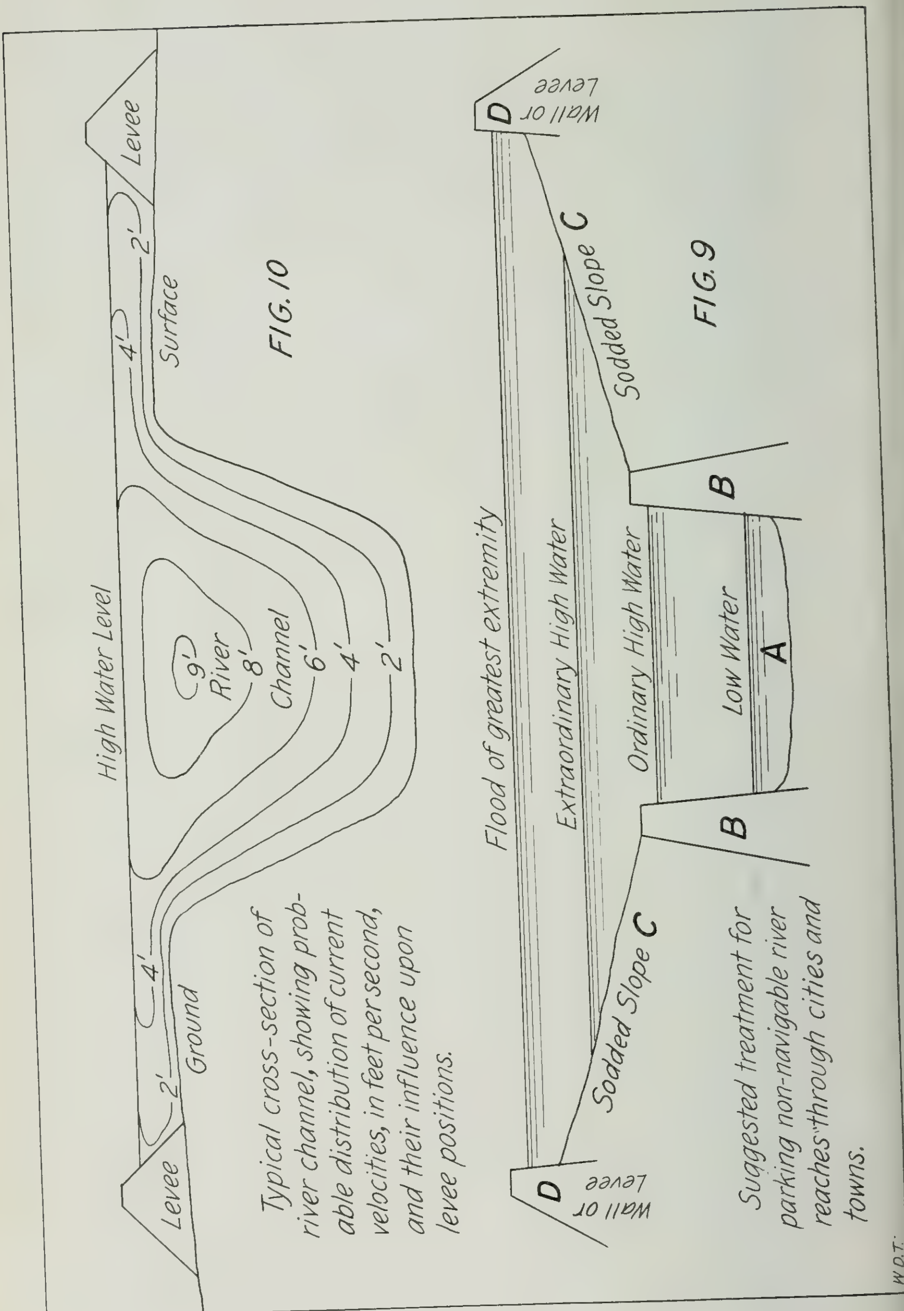


FIG. 10

Typical cross-section of river channel, showing probable distribution of current velocities, in feet per second, and their influence upon levee positions.

FIG. 9

Suggested treatment for parking non-navigable river reaches through cities and towns.

increased for any effective distance. The first direction has the greatest possibilities of the three. It was at first proposed to relieve the Miami Valley thru Butler County in this way, but it was soon found to be extravagantly expensive. It was also proposed to relieve Columbus in this way, and the proposition was put to vote. It was defeated, but only by a small margin. Such a plan, (widening the channel), is necessarily restricted in benefit to local situations. It becomes too expensive to obtain widespread benefits from excessive floods in this way.

Had our river cities in the beginning the knowledge they have now, the safe passage of floods thru their confines might be provided for as shown in Figure 9. That is, the city would be so laid out that the river-reach would form a park. The walls BB would confine the ordinary stages A. Excessive floods would extend onto the sodded slopes CC, and floods of greatest extremity would be confined by walls DD. Many modifications of this general scheme will suggest themselves, such as having driveways at the foot of or on top of the walls DD, or of variously terracing the sodded slopes CC, and so forth. The walls themselves might be of concrete, or sodded levees, or combinations of the two.

This plan would apply especially to towns to be built on smaller non-navigable streams. It would involve a reversal of our present custom of making sewers out of rivers thru towns, but then it would be more sanitary to treat our sewage and trade wastes in another way. Water is naturally an attractive feature and the natural place for a park is along a stream. The sodded parks CC could be given any inclination or terracing desired and ordinarily would be one of the cheapest protections against scour, both in first cost and in maintenance.

The effect of sod in resisting scour is strikingly shown in the accompanying photograph, taken at the east entrance of Greenlawn Cemetery in Columbus, immediately after the flood of March, 1913. The flower bed was filled with earth and flower bulbs before the rise. The flood water, then sweeping over the ground five or six feet deep, whisked the earth out of the flower bed and downstream, ate into the well-packed macadam roadways on either side, swept the macadam from the driveway on the upstream side across the grass plot, depositing some of it in the flower bed as shown. *Note that the 12-inch sod strips perfectly protected the ground beneath, from a current which destroyed macadam driveways.* Other striking instances of the resistance of sod to scour were photographed, which are not reproduced here. Instances occurred in the same flood where rocks weighing 40 or 50 pound were swept across grass plots which remained undisturbed. It is sufficient to recall that sod has preserved works of the Mound builders in this State thru much longer periods of time than those which have crumbled masonry structures in this climate. The use of grass to protect levees on the lower Mississippi is a practical application of the prin-

Illustration of the Protecting Power of Sod Againist Erosion. (Photo by F. H. Haskett)

ciple. It is thought well to emphasize here the effectiveness of this simple and attractive remedy, which ought to be used extensively thruout the State, not only on levees, but also for highway and railway banks and cuts.

Flood damages thru cities are usually increased by the encroachments on natural channels. Those interests occupying stream banks often count it pure gain to fill in a portion of the natural channel. Much of the original channel of the Scioto thru Columbus has been gradually preempted in this way, and the same situation prevails on many other streams of the State. It is a matter requiring regulation, and some States (notably Pennsylvania, by legislative enactments of May, 1907, and June, 1913, vesting supervisory powers in the Water Supply Commission) have assumed the proper responsibility of regulating encroachments. Bridge clearances come under the same category, and it has recently been proposed that the Federal authorities take charge of supervising bridge clearances on all streams from mouth to headwaters. (See Report of Ohio Flood Board, October, 1913, House Document 246, 63rd Congress, 1st Session.)

Likewise the occupation by buildings of the natural flood plain of a river, results in increased flood hights thru such cities. Columbus is a case in point, where the West Side residence district extends entirely across the flood plain a mile and half wide. Dayton is even a more pronounced instance, the center of the city occupying the natural flood plain. In such cases, the buildings constitute a leaky dam across the valley, raising flood waters to above their natural hight.

(2) The use of *levees* is virtually another way of increasing the channel cross-section and resultant carrying capacity of a river. Levees have been used extensively on the lower Mississippi and appear to be the only economic method of caring for floods in that region. Their proper construction out of various materials is an art in itself, and those interested would do well to read William Starling's able and charming book, "The Floods of the Mississippi River." Figure 10 accompanying is taken from the 1912 report of the Texas levee and drainage commissioner, and shows the typical position and effect on velocity of water of levees as applied to the Brazos and other streams of that State. It applies in general to other streams as well. Levees in certain instances may be set back some distance from the river banks, in which case the area between them and the river proper forms intermittent reservoirs, full only in times of flood and available for agriculture in intervals between. This principle has received application on a number of streams.

The disadvantage of levees is that they interfere with drainage from the lands which they protect from overflow of the main stream, so that if while the leveed river is in flood, it also rains on the leveed land, backwater collects, which must either be pumped or allowed to stand until the river subsides sufficiently. The value of the land may warrant expensive

pumping. The dikes of Holland, the drainage districts along the Mississippi in Illinois and Louisiana, and the city of New Orleans are well-known examples.

Another objection to levees, raised by some people is the danger of their failure. This objection of course applies to any works of man not properly constructed. Levees can be safely built out of any kind of soil if properly proportioned and bonded to foundation, This has been demonstrated with the soft soils of the lower Mississippi. The section need not be excessive. It is only necessary to maintain its upper surface at all times above the water-table within the levee. The mode of failure of levees is usually by wearing or sloughing away from the rear or land side, due to their being overtopped and not sodded. Some striking photographs of this taken by F. H. Haskett, University Photographer, under the writer's direction, could be presented here were space available.

(3) *Increasing the grade or slope of a stream,* thereby increasing the velocity and discharging capacity of a given section, is usually accomplished by cut-offs, that is, by cutting thru bends, thus straightening the channel. This has been applied to many small streams in land drainage, and has often been proposed by laymen for improving the lower Mississippi. Starling stated in 1897 that the river had then practically the same length it had in 1825. "Yet within the interval of 72 years, there have occurred at least 14 cut-offs, with a shortening of at least 160 miles or so." (Floods of the Mississippi River, Page 53.) It is evident from the behavior of the Mississippi that cut-offs may not be a universal remedy.

(4) *Diverting a portion* of one drainage basin to another is a trick, that has often been practiced by nature itself in the past. Geologists are familiar with the phenomenon under the name of stream piracy. Whether man can economically practice it or not depends on how far nature has already carried the process. In other words it is a matter of topography. Perhaps the most familiar example to us of artificial diversion is that of the Chicago drainage canal, diverting lake water down the Mississippi. Lake Michigan used to drain into the Mississippi in early glacial times, as did also Lake Erie. The Chicago diversion is but a restoration, on a small scale, of early natural conditions. The divide between the Lakes and the Gulf affords several interesting instances of diversion possibilities aside from that of the Chicago canal, one of which is in central Ohio and will be touched on at length on later pages.

(5) *Detaining or impeding dams* have as yet been little used in this country for flood protection purely. They are constructed so as to allow ordinary floods to pass thru holes in the dam of such size that extraordinary floods are impeded and accumulate back of the dam, so long as

the volume of the flood water exceeds the discharging capacity of the holes or sluices. *A detention basin* is thus created back of a detaining dam which is dry and available for agriculture in the intervals between floods. Such a dam would be the most advantageous in regulating a stream in a valley too narrow for effective storage reservoirs, and where no purpose other than the diminution of excessive flood hights is to be served. The great Assuan Dam, at the first cataract of the Nile, with its sluices is virtually an impeding dam, altho it secures much more than flood protection.

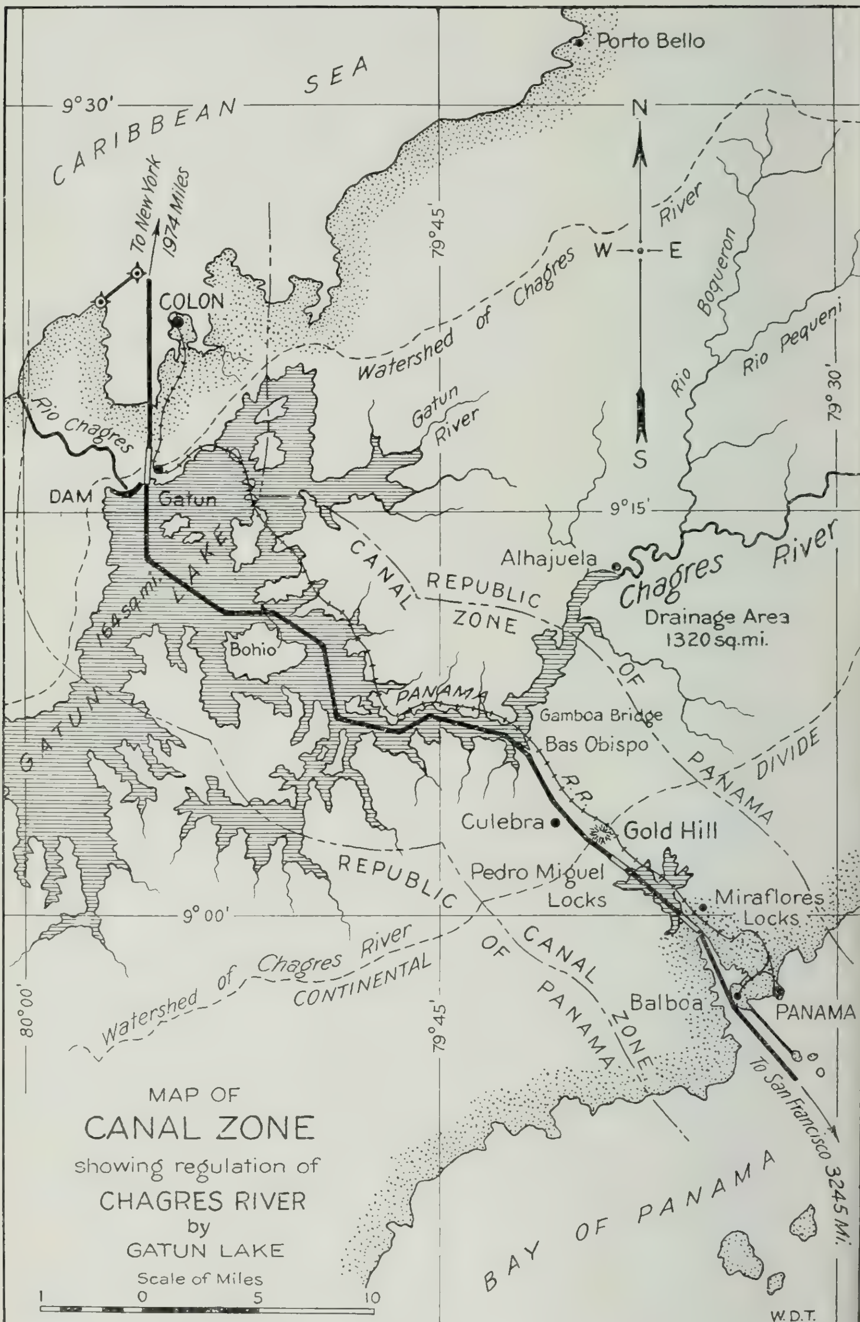
(6) The effect of *storage (impounding) reservoirs,* on stream flow, is illustrated at many places in nature, most striking of which is the effect of the Great Lakes on the St. Lawrence River. The Lakes might be regarded as widewaters of a river extending from Duluth to Quebec, in which the maximum difference between high and low water is only a foot or so, requiring a year to accomplish this change. The most striking example of the effect of artificial impounding reservoirs on stream-flow is perhaps Gatun Lake at Panama. (See accompanying cut.)

The heavy line in the drawing shows the route of the canal. There were five great problems in its construction, (1) overcoming preliminary political obstacles, (2) ridding the region of formidable disease, (3) the control of the wild river Chagres, (4) securing suitable foundations for the canal's massive structures, and (5) efficiently organizing the work for economical prosecution. The great engineering difficulty was the third of these problems and it was solved by adopting a lock-level canal in place of one at sea-level, and by building a great dam at Gatun, instead of at Bohio, Gamboa, or other points, as previously proposed.

The Chagres River at Gatun, has a drainage basin of about 1320 square miles, (but little larger than that of the Scioto above Columbus). It is an exceedingly violent stream, experiencing, every year or so, floods of equal or greater severity than that occurring March, 1913, on Ohio streams, with the difference that the rises occur more suddenly on the Chagres. For example at Vigia on the Chagres, where the drainage area is less than that of the Olentangy at Delaware, in December, 1910, the water rose more than 40 feet in 8 hours, washing out the observer's house and instruments. Compare this with a rise of 24 feet,* in a period of twenty-four hours or longer, on the Olentangy at Delaware, where the flood of March, 1913, reached a greater proportionate hight than at any other point in the State.

Such sudden and frequent floods scour the banks of the Chagres and tributaries, bringing down large quantities of gravel and silt, which would

*Four feet of this was due to the Big Four railroad bridge, leaving 20 feet above low water as the unaffected hight reached.



Porto Bello
CARIBBEAN SEA
9°30'
N
W E
S
To New York 1974 Miles
COLON
79°45'
Watershed of Chagres River
Rio Boqueron
Rio Pequeni
79°30'
Gatun River
Rio Chagres
DAM
Gatun
GATUN LAKE 164 sq. mi.
9°15'
Alhajuela
Chagres River
Drainage Area 1320 sq.mi.
CANAL ZONE
REPUBLIC OF PANAMA
Bohio
PANAMA R.R.
Gamboa Bridge
Bas Obispo
CONTINENTAL DIVIDE
Culebra
Gold Hill
Pedro Miguel Locks
Miraflores Locks
9°00'
Watershed of Chagres River
CONTINENTAL
80°00'
79°45'
Balboa
PANAMA
To San Francisco 3245 Mi.
BAY OF PANAMA
MAP OF
CANAL ZONE
showing regulation of
CHAGRES RIVER
by
GATUN LAKE
Scale of Miles
1 0 5 10
W.D.T.

be deposited in the canal in most instances were these streams to empty into the canal, which would be the case for many small streams were a sea-level canal adopted. But by creating Lake Gatun five objects were accomplished at one stroke, (1) the reservoir reduces the violent floods of the Chagres to fluctuations of two or three feet a year, (2) by backing the water up the main stream and tributaries it prevents scour from reaching the canal, (3) it reduces the amount of scour or silt by reducing the area subject to erosion, (from the map it will be seen that the lake extends almost up to the river divide along the Atlantic), (4) it furnishes more than 20 miles of navigable route, and (5) stores surplus water for power and other purposes.

The dam also, by raising the lake surface to an elevation 85 feet above mean sea-level, backs the water thru the Culebra cut to Peter McGill locks on the Pacific side, and enables the Chagres River to be drained into the Pacific, if such were desirable. However, such an ample spillway is provided at Gatun Dam, that water not needed, is turned down the old bed of the stream.

The foregoing paragraphs sufficiently illustrate the difference between impeding dams with intermittent, or so-called dry reservoirs, and impounding reservoirs. The latter serve many more uses than do the former. Impounding reservoirs, however, have one defect as flood mitigators—they may be full when an excessive rainfall begins. They are, therefore, not so effective as detention basins for the one purpose of decreasing flood hights. Nevertheless, they do reduce flood hights even if a flood comes when they are full, in a way somewhat closely proportional to the ratio of reservoir area to drainage basin area. The Great Lakes, comprising about 25% of the St. Lawrence drainage basin, and Gatun Lake comprising about 12.5% of the Chagres, are almost perfect regulators of their respective rivers, even tho those reservoirs may be full when floods come. One never hears of a flood on the Detroit or Niagara River for the reason just given. Because of the varying conditions on each stream, it is better to take a concrete example for Ohio, which we do in discussing the Sandusky-Scioto conservancy project.

(7) A measure of the value of *reforestation* as compared with other methods of reducing flood hights is also afforded at Panama. Before Lake Gatun was created, the Chagres River was continually swept thruout by violent floods, notwithstanding the fact that its drainage basin is covered with a denser jungle than is possible to grow in Ohio. Of course, the annual rainfall on the Isthmus is much greater than it is here, but the instance is cited to show that forests are not effective stream regulators there. Reforestation has been proposed so often as a flood preventative or palliative, that a great many people have come to regard it as a universal remedy. This is far from the truth. It might be effective in

some parts of the world under favoring circumstances, but it does not apply to Ohio. Some of the worst floods we have experienced have been in the most thickly wooded parts of the State. Two recent cases in point were the Duck Creek flood of July 14, 1913, and the flood east of Steubenville, August 26, 1912. Both these floods occurred in valleys with but little population, so that they were little heralded at the time, but they exceeded in violence any floods yet recorded in valleys of similar size in our State.

It is true that both floods just cited were in steep hilly regions like that of southeastern Ohio, which added to their violence, but experience in wooded gullies of southeastern Ohio extending over a number of years has satisfied the writer that forests have little effect on those streams even at headwaters. For example, in 1901 and 1902, the sites of the summer surveying camps of the Ohio State University were located on small streams in thickly wooded tracts in Vinton and Morgan Counties, respectively. It was thought before locating camp that because of the wooded areas enough water could readily be furnished from each stream for camp purposes during the period of encampment, lasting from the middle of June to the middle of July each time, yet great difficulty was experienced in obtaining sufficient water thruout that period, altho violent floods invaded both camps during each of the periods mentioned. The heavy storms shown in Figures 5 and 8, fell on regions more thickly wooded than the average of the State.

Again taking conditions prevailing in March, 1913, on the flatter drainage basins above Dayton and Columbus, it can be seen that it would be impracticable by reforestation to materially lessen the damage caused by such a storm as was then experienced. At the time of the storm the trees were leafless, the ground was saturated and the streams had been running at moderate stages for a week or more preceding. Along the state divide on Easter Sunday, March 23, was precipated an inch or so of rain, before the heavy rainfall shown in Figure 4 began. Suppose the whole area to have been covered with forest. The forest floor might have acted as a sponge, but a sponge already saturated would have stopped little of the deluge which then dropped on it.

The impracticable part of using reforestation to stop such a flood, is that all the valuable farm lands in these basins cannot profitably be wooded. The lands in these basins include much of the richest land in the State. Forests at present cover less than 10 per cent of the area, and these woods are in small scattered lots as indicated on the State Topographic Survey maps. The great economic demand is for more cultivable instead of more timber land in such a thickly populated State as ours, so that it is doubtful whether the present forest areas in these basins can profitably be doubled. If doubled, the amount of forest area would not exceed 20 per

cent of the basins, and the writer believes that this amount would not affect appreciably either dry or wet weather flow in main streams.

The writer would not be understood as being hostile to forestry interests. He is a tree-lover, and spends vacations when possible in the forests in preference to other places. He believes in all measures looking to intelligent forestry in the State but cannot avoid the conviction, from an examination of many specific instances, that reforestation, so far as practicable, cannot materially affect our stream-flow. The merits of reforestation should be based on other considerations.

Reforestation or afforestation as a flood mitigator, must be considered in detail with special reference to its effect on a given stream. Its effect on Wisconsin streams has been so studied by Prof. D. W. Mead, who concluded that it exerted no material effect on those streams. See Bulletin 425, University of Wisconsin, May, 1911. The United States Department of Agriculture is now conducting an experiment at Wagon Wheel Gap, Colorado, intended to cover a period of years on two western streams. Until it has been so extensively studied with reference to a given stream, its value as a flood regulator cannot be known. *It is at present the most uncertain of all methods of stream regulation; as applied to Ohio conditions, reforestation is undoubtedly the most expensive and least effective.*

As a general remedy elsewhere the National Waterways Commission in 1912 unanimously concluded that—*

> Whatever influence forests may exert upon precipitation, run-off, and erosion, it is evidently greatest in the mountainous regions where the rainfall is heaviest, slopes steepest, and run-off most rapid. Here also the land is less useful for other purposes. The extent of the influence of forests upon these three factors varies greatly, according to circumstances involved in each case. Under one set of conditions, forests may benefit stream-flow and mitigate floods, while under other conditions they may have the opposite effect. *In no case can they be relied upon to prevent either floods or lowwater conditions.*† There is substantial agreement on this point. Nor is their influence extensive enough to warrant their use as the only means of securing the uniformity of stream-flow which is desirable for navigation or the development of water power. For this purpose storage reservoirs would be much more effective.

*Final Report 1912, page 36.

†Italics in the above quotation are those of the present writer.

Combinations of Methods. It will readily be surmised from what has preceded, that two or more of the seven listed methods of mitigating flood damage may often be combined to advantage in a given project. For example, the use of levees in connection with increasing channel capacity by clearing out obstructions, might be applicable to the lower Scioto from Columbus to Portsmouth. On the lower Mississippi at places, levees are set so far back from the river bank that in confining extraordinary floods they virtually form intermittent or "dry reservoirs," between levee and river bank, this area being available for grazing or agriculture in ordinary seasons. On a smaller stream this practice might not be safe, but on the lower Mississippi, floods can be forecasted weeks in advance, in time to get live stock out of the affected area.*

Another practicable combination is that of combining the good features of impounding with intermittent reservoirs. This is well illustrated by the project of the New York Water Supply Commission (see annual reports for years 1909, and 1910) on the Genessee River at Portage, upstream from Rochester. Here a masonry dam 152 feet high (from bottom of foundation to top of coping) would form a reservoir of 13.3 square miles area when full. The lowest portion of the dam is ineffective except to secure proper foundation. The next stratum of water above, 45 feet deep or thick, would be used only during low water conditions to maintain a good dry-weather flow. The next stratum of water above, 55 feet deep, containing about 11 billion cubic feet, would be used for power generation, (reinforcing and making more dependable the water powers already established, or to be established on the stream below). The top stratum next above, 17 feet deep, containing about 6 billion cubic feet storage capacity, would be used for flood catchment, and would be kept empty between floods. When the reservoir filled to within 17 feet of the top, automatic flood regulation ports would begin to spill the water, and at an elevation 15 feet higher the water would discharge over a spillway.

At the site of the dam the river discharge now varies from 80 cubic feet per second in low water to 42,000 second-feet in time of great flood. The dam would regulate such flow to a maximum of 12,000 cubic feet per second. The dam has not been built, because as yet they lack sufficient legal authority to meet the various obstacles encountered. In Ohio, since the passage of the Conservancy Act in 1914, and the declaration of the constitutionality of its main features by the State Supreme Court in 1915, such a project could be readily carried out.

*See Floods of the Mississippi, by William Starling.

Conclusions as to Flood Plans.—It has been shown in the previous chapter that no two flood-causing storms are alike. Likewise that every stream is a law unto itself. Therefore, every flood protection or stream regulation project will form a special problem, calling for extensive study and first-class engineering talent. The more extensive the district to be treated, the more numerous the flood protection methods either singly or in combination, will it likely bring into play. This is well illustrated in a later chapter on the Sandusky-Scioto Conservancy project.

We have seen in discussing flood possibilities that *only partial protection is economically feasible.* It is not wise, therefore, at present, to provide for much greater hights than those we have had on our main streams, except as the growing value of property warrants some extra expenditure, and as the local conditions on each stream permit the additional protection to be obtained at rapidly diminishing comparative cost. After such plans are prepared it must be realized that extreme local floods may occur on smaller streams, against which it is economically impossible to provide.

The following unanimous conclusions of the National Waterways Commission in its final report of 1912, (page 26), altho meant for general conditions over the country, are interesting here and now. (The italics in the quotation are the writer's.)

After careful consideration of the problem of utilizing storage reservoirs for flood prevention, the commission has arrived at the following conclusions:

1. "As the country develops, the necessity for controlling floods, becomes of greater importance, both in respect to improved property in thickly populated districts and to valuable unimproved lands which are needed for agricultural or manufacturing purposes. Losses from floods are not confined alone to the destruction or damage of property, but also result from the inability to utilize large areas threatened by floods. In the case of many streams the adoption of some means of flood prevention has already become most urgent, because of the constantly increasing losses due to floods.

2. "The use of storage reservoirs as a means of controlling floods, although expensive, becomes more practicable where the value of property liable to damage is great and where the reservoirs can be used simultaneously for other beneficial purposes, such as power development and aiding navigation. The question of feasibility of storage reservoirs depends upon the relation between the cost of construction and the benefits to be derived in each particular case, and the benefits increase rapidly as the country develops. *The time has already come, especially in the more thickly settled river valleys, when a stream must be considered with a view both to minimizing its harmful influences and to securing the maximum benefit from all its uses.*

3. "The lack of adequate information makes it impossible for the commission to specify on what streams the construction of reservoirs would result in benefits commensurate with the cost. In most cases little is known con-

cerning stream-flow and the physical conditions causing floods, or whether there does exist reservoir sites suitable to afford the necessary relief. The extent of damages caused by floods on different streams has not, as a rule, been accurately determined, nor have investigations been made to ascertain relation of the cost to the benefits that would be derived from the construction of reservoir systems. The commission is of the opinion that each case must be considered on its merits, after a thoro investigation of all the facts and strongly urges the necessity of careful studies such as the one recently made by the Pittsburgh Flood Commission.

4. "The Federal Government has no constitutional authority to engage in works intended primarily for flood prevention or power development. Its activities are limited to the control and promotion of navigation and works incident thereto. The commission is of the opinion that flood prevention is primarily a local problem, and the work of controlling floods should in the first instance be undertaken by the minor political subdivisions, but that the Federal Government may very properly participate with the localities in carrying out such works on navigable streams, where a substantial and necessary improvement to navigation will result. Unless some such policy as this is adopted and adhered to, there is grave danger that the Federal Government may go outside its proper jurisdiction and become involved in enormous expenditures which are for local benefit. It has sometimes been urged that the Federal Government should undertake works for flood prevention on non-navigable streams which happen to cross a state boundary line. It is clear that in such a case, if navigation is not concerned, the Federal Government should have nothing to do with flood prevention. A method is provided in the Constitution by which the states may cooperate for this purpose.

5. "The extent to which the Federal Government should participate in the expense of constructing a reservoir system at the headwaters of a navigable stream should be determined in each particular case by an investigation of Government experts possessing the necessary training and facilities for undertaking a study of this nature. If such investigation shows that the promotion of navigation will require the reenforcement of the flow of a stream during the dry season through the aid of storage reservoirs, and shows the number and cost of reservoirs necessary for this purpose, the Federal Government will have a satisfactory basis for sharing in the expense of constructing a larger system intended also for preventing floods. In this connection it should also be noted that the prevention of floods will indirectly benefit navigation, but this alone is not sufficient reason for the participation of the Federal Government in reservoir projects."

In this connection it should be noted that Ohio is fortunate in having practically all its main streams within its own bounds, so that projects may be executed without the complication of joint state action. Ohio River lies without the State, low water mark on the north shore being our southern boundary. Such flood protection projects as would effect navigability of the Ohio will call for joint Federal action. An example of this is treated of in Chapter VIII.

CHAPTER IV

ECONOMICS OF WATER TRANSPORTATION

Will inland navigation pay? We will consider here chiefly transportation on rivers and canals, with occasional reference to lake and ocean trade. So much has been written on the topic, and the controversy has raged so bitterly *pro* and *con*, that the general state of mind on the subject is one of confusion, or of blind acquiescence to one side or the other.

In the controversy between railroads and waterways, the advocates of the latter, in making comparisons of efficiency, have usually failed to include in water transportation costs, interest on first cost and the cost of maintaining the waterway. These two items of expense on waterways are usually borne by state or national governments, at least in large degree, while railroads have to bear such expenses themselves and must care for them in charges to their customers.

Also in Ohio the railroads pay, to each taxing district in which they lie, taxes on their property, assessed at full value, and they pay an excise tax of 4% to the State on all intrastate gross earnings. Also a large proportion of the cost of maintaining the Public Utilities Commission, is charged to steam railroads. The Act of 1910, which fixed the excise tax on steam railroads at 4%, fixed an excise tax on interurban and water transportation companies at 1.2 per cent.* When the restrictions additional to those already mentioned laid by state and national authorities on steam railroads are considered, the latter certainly have the sympathy of the writer.

If tolls were eventually to be charged on all waterways sufficient to maintain them and pay for fixed charges, we would then have a fairer basis on which to compare transportation costs.

The abolition of tolls on many state waterways, and the national policy of paying from federal funds the first cost and maintenance of interstate navigable streams, leaving railroads to bear these similar charges for themselves, has naturally caused antagonism instead of cooperation between railways and waterways in the past. It is, therefore, not surprising that in some instances railroads have purposely smothered waterway competitors. Public favoritism has usually been shown to waterways, while the opposite attitude has too often been taken with regard to railroads, more especially in recent years by various state legislatures. For example steam railroads in Ohio pay 65 per cent of the cost of grade crossing eliminations, the balance being divided between the city and an electric railroad if the latter uses the street.

*See annual report of Ohio Tax Commission of December 15, 1911.

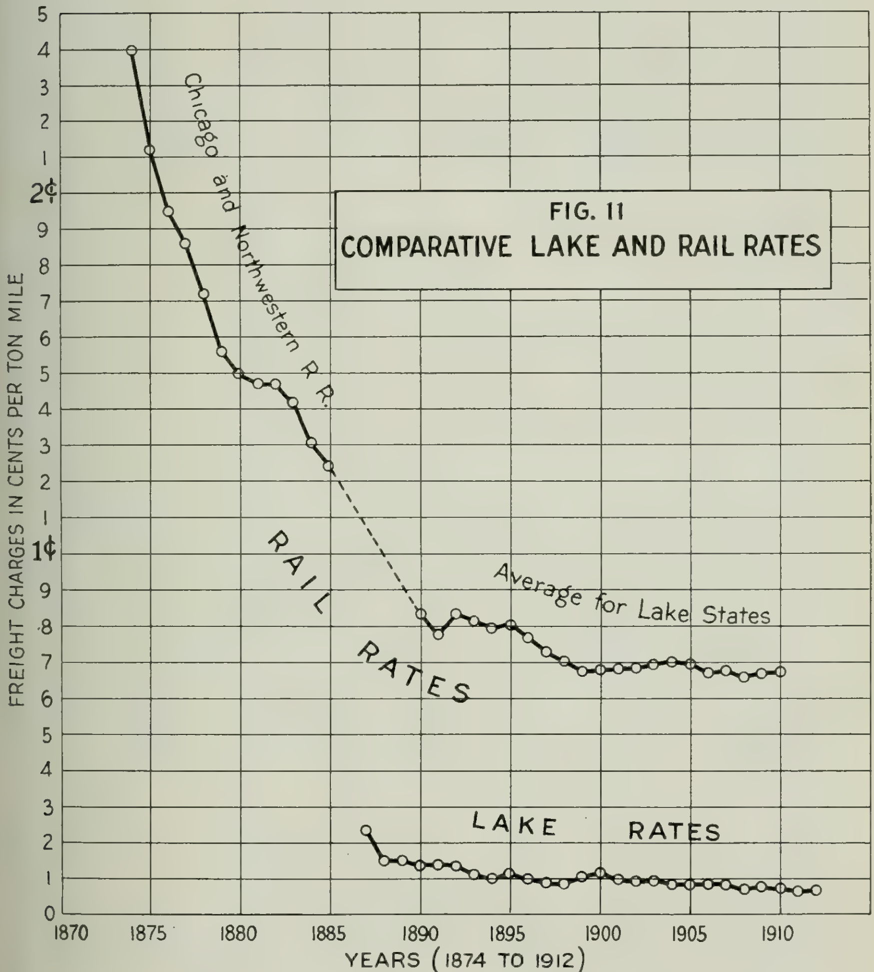
It is well to reflect that more than half the railroad mileage in the country has at one time or another, been in receivers' hands, and that for the past decade or more, there has been no great anxiety on the part of private capital to invest money in railroads as compared with other enterprises. Yet it is doubtful whether any other form of private investment has brought the State and nation more benefit.

The writer is a great admirer of the American railroad and believes that if one will take the trouble to inspect the railroads of Europe and allow for labor and other conditions there, he will conclude that the American railroad is, on the whole, the most efficient in the world as regards freight and probably as regards passenger transportation. But, it would appear, that waterways also have a place among instruments of transportation, which should receive unprejudiced consideration. A finding of fact, so far as is possible, is therefore desirable concerning both instruments.

It would seem that we have almost reached a practical limit of cost of carrying freight on our best railroads, unless the heroic and economically doubtful expedient of widening gage is resorted to thruout the country; because with our standard gage the largest engines and cars now in use practically fill available clearances. There are only three directions for an engine to expand, laterally, vertically and longitudinally along the track. They have expanded in the first two directions as far as is safe with five-foot gage, and have lately been expanding longitudinally until they have reached nearly practicable limits. The heaviest Mallet compound engines now are nearly 120 feet long with tender, and weigh 850,000 pounds or more.

With grades reduced almost to the limits set by drainage, the most favorable directions for increasing carrying capacity, and thereby reducing cost, is usually in double tracking, or in limited cases in resorting to electrification. This last expedient is confined chiefly to regions where water power is abundant, grades unusually steep, and fuel costs high. Improvements in the foregoing respects, together with increasing efficiency in management, more especially in solving the ever present problem of securing better train loads in both directions, will reduce rail transportation costs in the future. But it is believed that rail rates in this region have experienced by far the greater part of their decrease; that the decreases in the future will be small as compared with those in the past; and that in some instances railroad rates have now been forced down too low for the character of service they can and should render. The earnest requests of our railroads for an increase in rates during the past five years, argues the truth of the foregoing situation.

The truth of the first two of the three foregoing statements is evident from the accompanying diagram (Figure 11), showing the decrease in rail rates since 1874. The diagram likewise shows the decrease in lake rates



Rail rates for Lake States (Ohio, Indiana, Illinois, Michigan, Wisconsin, Minnesota) are from column 5 of Table IV. Lake rates are from column 2. See footnote under table, and remarks in text accompanying.

since 1887. (See also Table IV from which Figure 11 is plotted.) The latter rates are taken from the Statistical Report of Lake Commerce for 1912, and date from the time when accurate records first began to be kept by the Army Engineers. The rail rates are taken from the Statistical Reports of the Interstate Commerce Commision, from 1890 to 1910, for the states adjoining the Lakes, Groups III and VI.* These groups of states combined have lower average rail rates than any other two groups in the United States. (See Statistical Report of Interstate Commerce Commission for 1910, page 59). They were chosen for the reasons given at the bottom of Table IV.

The government records of rail rates prior to 1890, are not available, and the diagram has been extended back to 1874 by using the rates of The Chicago and Northwestern Railroad as extracted from Wellington's Economic Theory of Railway Location, page 35. This railroad has been chosen because it lies mostly in a district whose traffic is most directly comparable to lake traffic, and because it has been operated with efficiency in the past.

Four striking observations may be made from the diagram: (1) Altho the railroads have been selected in regions whose traffic is most nearly like that of Lake traffic, and in the two regions taken together (Groups III and VI), in which rail rates average lowest in the United States, they have almost uniformly been seven to ten times higher per ton-mile than those on the lakes. (2) The period of most rapid improvement in transportation methods by rail with consequent reductions in rates ended about the year 1900, while those on the lakes show a slight gradual decrease since that time. (3) The curves for the past five or ten years have run nearly level, that is, there has been no great reduction in rates. (4) Little reduction (as compared with the past) now remains probable, the curves are so near the bottom and practically parallel thereto.

It may be objected that it is unfair to compare Great Lakes with rail rates because the latter include high-class freight, while lake traffic consists mostly of low-grade stuff, such as coal, ore, grain and lumber; also that the average haul is long while the average rail haul is short. Both of these contentions are true. But the ratio of rail to lake rates (on the average eight times) is altogether too great to be accounted for by the two foregoing considerations alone. The causes of the great difference require to be examined, which we do on pages following under ten captions on advantages of water transportation.

It is not probable that rail rates on our best roads on *low-grade* freight will fall below two mills per ton-mile for a long period in the future. The average cost now of low-class freight on some of our best roads is more

*Since 1910 the statistics for these groups separately have not been published by the Interstate Commerce Commision, and hence are not available.

TABLE IV
COMPARATIVE LAKE AND RAIL RATES

Mills per ton-mile

YEAR	LAKE	RAIL			
		GROUP III	GROUP VI	AVERAGE OF III & VI	AVG. FOR WHOLE U.S.
1	2	3	4	5	6
1887	2.30				
8	1.50				10.01
9	1.50				9.92
1890	1.30	6.95	9.61	8.280	9.41
1	1.35	6.90	8.58	7.740	8.95
2	1.31	6.74	9.83	8.285	8.98
3	1.10	6.63	9.62	8.125	8.78
4	0.99	6.36	9.42	7.890	8.60
5	1.14	6.42	9.61	8.015	8.38
6	0.99	6.18	9.17	7.675	8.06
7	0.83	6.05	8.55	7.300	7.96
8	0.79	5.78	8.26	7.020	7.53
9	1.05	5.29	8.21	6.750	7.24
1900	1.18	5.46	8.06	6.760	7.29
1	0.99	5.68	7.89	6.785	7.50
2	0.89	5.76	7.87	6.815	7.57
3	0.92	6.07	7.74	6.905	7.63
4	0.81	6.20	7.79	6.995	7.80
5	0.85	6.07	7.66	6.865	7.66
6	0.84	5.94	7.45	6.695	7.48
7	0.80	5.98	7.43	6.705	7.59
8	0.69	5.94	7.35	6.645	7.54
9	0.78	5.89	7.48	6.685	7.63
1910	0.74	5.88	7.51	6.695	7.53
1	0.67				7.57
2	0.67				7.44
3					7.29
4					

Lake rates are extracted from reports of Army Engineers, Detroit office. Rail rates are from statistics of Interstate Commerce Commission. Groups III and VI comprise the North Central States. This region has comparatively low grades, cheap fuel, and freight traffic most resembling that on the Lakes.

nearly twice the above figure. For example on The Hocking Valley Railroad, which has chiefly a heavy traffic in coal and which is operated as a three-tenths per cent road (which is a much lower grade than the average railroad of the country has), the costs per ton-mile are between three and four mills for a haul of 200 miles or more. Its charges must be four mills or more to make a return on the investment.

What is the situation with regard to transportation on water? It would appear from an examination of the essential items that make up the cost of transportation, that waterways have some inherent advantages over all other ways of transportation, and some inherent disadvantages. These all need to be carefully considered in projecting improvements for cheapening transportation in this country.

Advantages of Water Transportation

(1) *The power required* to move one ton horizontally (that is, on a level track,) is less on water than on any other way. Using horses and wagons it requires from 100 pounds to 33 pounds as a minimum on a first-class dustless level road and a well-paved level street respectively. On a level railroad without curves and with track and rolling stock in good condition, it requires 4 pounds as a minimum. This is at a speed of about 10 miles per hour. The resistance increases with lower speed than 10 miles, contrary to that on water. Train resistance will average more nearly 10 pounds on level track with necessary curves, and it increases with speeds greater than 10 miles per hour. Less than 1 pound per ton will suffice to start a load on water, the resistance increasing with the speed up to about 5 pounds per ton under average conditions for a speed of about 5 miles per hour in water 9 feet deep. (See report on Experimental Towboats, by Army Engineers, published 1914.*)

(2) *The advantage of grades* is with waterways over that of all other tracks. Waterways have level grades, or grades practically level, vertical lifts being accomplished by locks where necessary. On highways grades will vary with the topography of the country. The various grades on city streets and country highways are familiar examples, and these grades add to the tractive power necessary to move loads over level stretches. The maximum grade on either a highway or a railway sets the limit of loads passing over them. Thus a grade of one per cent that is, one foot rise in 100 feet horizontally, on either a railway or a high, way, requires 20 pounds of tractive force per ton in addition to the force required to move the ton load on a level. The force required on grades varies directly with the slope, being 2 pounds for each tenth of one per cent grade.

*House Doc. 857, 63d Congress, 2nd Session.

(3) *The ratio of paying to dead load* is much in favor of waterways over vehicles on every other form of way. The importance of this point is not usually perceived by the average reader. Thus a wagon designed to carry 10,000 pounds of load, will itself weigh 3000 pounds or more. If it were more lightly built, it would not last long. Therefore the horses in pulling five tons of freight, pull also a ton and a half of wagon. That is, the ratio of dead load to paying load is 30 per cent. The ratio in motor trucks at present runs much higher still. On railways, a modern freight car of 100,000 pounds capacity will weigh between 35,000 and 40,000 pounds, that is its weight will average 37 per cent of its carrying capacity. In ocean freighters, this percentage is less than that of wagons; on lake carriers less still; and on Ohio River barges, the ratio drops to about 15 per cent.

(4) *The first cost of vehicle* per ton of carrying capacity is in favor of river barges over all other vehicles. Wagons cost \$25 to \$30 per ton; motor trucks from \$500 to \$1,000; freight cars, \$25 to \$30; ocean carriers, \$70 to \$100; lake freighters, \$30 to \$50; river barges from \$4 to \$9, for wood and steel respectively. The motor truck, ocean and lake prices, however, include motive power installed on vehicle.

These figures, however, do not afford complete comparison, because of the varying average speed with which vehicles move, which affects their carrying capacity per annum, (which is the proper basis when first cost is compared). If these averages in miles per hour thruout the year be taken as 1, 3, 2, 8, 3 and 2 respectively for wagons, motor trucks, freight cars, ocean carriers, lake freighters, and river barges, the relative cost of vehicle per ton carried annually is twice as cheap for barges as for any other form, assuming the more expensive steel barges to be used.

The subject of average speeds brings up a large question too lengthy to discuss in full here. It involves discussion of the various delays incident to each form of traffic. Wagons may average two miles per hour during daylight, motor trucks say six. Lake freighters operate both day and night, but the navigation season averages only seven months per year. Ocean and rail carriers operate continuously, freight cars, however, being subject to the greatest number of delays. The reports of the Interstate Commerce Commission show that freight cars over the country have averaged little more than one mile an hour for the 8,760 hours in a year. We have doubled this figure, or used 50 miles per day, as the average car movement in the above computation.

On the Lakes, 18 round trips from Cleveland to Duluth (about 1,600 miles per round trip), is considered a season's work for an average lake freighter. This makes an average speed of 3.3 miles per hour for the year (instead of 3 used in the foregoing comparison), when five months are de-

ducted for the closed season due to ice in northern waters. This last consideration shows how various are conditions on different waterways, While ice at the latitude of Sault Ste. Marie, may close channels five months each year, at Memphis or New Orleans ice interferes not at all.

Ohio River barges now make the trip from Pittsburgh to New Orleans (1,927 miles) in 16 or 18 days during available stages of water. That is, they average nearly five miles per hour downstream while in motion. Proceeding upstream, loaded, they would average probably less than three miles per hour. They come upstream now empty at about the speed they go down loaded. When the Ohio River improvement is completed about an hour will be added at low water stages to the downstream time for each of the 53 locks, but the upstream trip will be as much or more expedited, so that the average speed in both directions, while the fleets are under way, may be taken at four miles per hour. Allowing ten weeks yearly average for closed navigation on the Ohio, the average barge speed for a year becomes 2.6 miles per hour, (for six round trips per year). We have used two miles as the average speed in the preceding comparison with rail and other ways. Army Engineers estimate in their report on Ohio River that ice will close navigation, on the average, only 10 or 12 days.

The subject of delays emphasizes the fact that each form of vehicle is suited to special service, that each form of transportation has its own field. Water carriers handling large units as they do are suited chiefly to long haul. It would not pay to stop large cargoes frequently on the way. Thus lake steamers thru the Soo carry each ton on an average more than 800 miles, while railroads in the two groups used for comparison in the diagram, haul each ton less than one-fifth this distance on the average. This longer haul operates to reduce ton-mile costs. However, in discussion under the present caption we have attempted to treat rail transportation fairly, in comparing it with water, by almost doubling present average freight car speeds, while reducing lake and barge speeds as already noted. A full discussion of delays would emphasize the fact that we should not lay any more artificial restrictions than we have to on any class of traffic, but should encourage each to develop to the highest efficiency in the service for which it is naturally best fitted.

(5) *The life of the vehicle,* that is, the cost of maintaining vehicles per ton of capacity, would seem to be greatly in favor of water carriers. Wagons and motor trucks are subject to more or less shock in passing over streets and highways which cannot be as smooth as vessel tracks. Everyone is familiar with the shocks freight cars sustain in switching around yards and terminals. Wheel wear incurred in transit is no inconsiderable item in freight car maintenance. Car repairs average 10 per cent or more of the total cost of operating railroads.

(6) *Cost of motive power.* The first cost of motive power (horses) for wagons is $150 or more per H. P. Lake vessels cost about $25, ocean carriers somewhat higher. The heaviest freight locomotives (costing about five cents per pound) cost about $15 per horse power. Towboats rigged complete for river barges cost from $60 to $90 per horse power installed. The latter figures are high because they include the cost of boat complete, with quarters for employees engaged in handling the barge fleets. The figures given for locomotives do not, of course, include quarters for train crew. The figures above given for lake vessels, likewise include only the cost of boilers and engines; for example, a lake vessel carrying 10,000 tons of load, would have 2000 horse power of engines and boilers installed, costing about $50,000, while the cost of the vessel complete would run about $350,000. Locomotives are thus cheapest in first cost.

But, the total cost of motive power is made up of *three main factors,* of which interest on the first costs above listed is only one, and the smallest one. The other two are operating costs, and the cost of maintenance. While interest on first cost is less per horse power on locomotives, fuel costs run much higher on locomotives than on marine engines. Thus a locomotive will burn 4 or 5 pounds of soft coal per horse power per hour generated, while marine engines burn less than 2 pounds. This saving in fuel alone on marine engines greatly outweighs the interest per annum saved on first cost of locomotives. Stoking and other motive power operating costs would be as cheap or cheaper on marine engines when reduced to horse power units.

Not only are operating costs on locomotives much higher, but maintenance charges per horse power are also higher than on marine engines. Five per cent or more of the entire cost of operating a railway goes for engine repairs and renewals. Many of the items entering this five per cent are due to racking and wear on rails, from which marine engines are free.

Average speeds should again enter into the comparison, in comparing ton-mile costs of motive power. If this is done, it will be found that the total cost of motive power per horse power mile, is still much in favor of water as compared with railways, even tho engine mileage, per locomotive, averages much more per annum than the annual mileage of freight cars.

(7) *The first cost of way* is difficult to compare, because circumstances differ so widely, and the annual capacity of way should enter into the comparison. It is unfair to compare the Great Lakes as to capacity with railroads or with highways, because the lake situation is unique, and would make the comparison far too favorable for waterways in general. We have, unfortunately, no extensive modern canalized river or canal from which to draw comparisons, for, such a waterway would have to be operated

sometime before its possible actual operating capacity could be well known.

The Ohio River may, however, be used to throw some light on the question. This stream, when completely canalized, (as is now being done by the national government) is estimated to cost about $75,000,000 from Pittsburgh to Cairo, 967 miles, or an average of about $77,600 per mile. (See report of Army Engineers in 1908.*) Its possible capacity thru locks (the latter are 110 feet wide by 600 feet long by 9 or more feet deep on sills) when built is estimated at nearly 100,000,000 tons per annum, exclusive of traffic thru the weirs or navigable passes.

A railroad of less than one-half this possible capacity would cost more than $100,000 per mile, because it would have to be double-tracked thruout, with numerous passing sidings and accessories to permit the handling of passenger trains interspersed between freight traffic. This last consideration illustrates one inherent difficulty in reducing freight rates on railroads; from the nature of things railroads must be relied upon for fast passenger transportation, and unless tracks are quadrupled thruout between termini, much time is lost by freight trains in giving way to passenger service.

On the Hocking Valley Railroad, for example, where low-grade freight is the great source of revenue, from three to five hours are lost by freight trains between the coal fields and the lakes due to delays from passenger service alone. It now requires from twelve to fifteen hours, or more including all delays, for a freight train to travel the 200 miles from the coal fields to the lakes. If passenger service were discontinued entirely this time might be reduced a third or a fourth, which would mean one-fourth less cars would be needed, one-fourth less road engines, one-fourth less train wages and one-fourth less of a number of others of the 116 items of operating costs kept in railway accounting.

For the New York Barge Canal now being completed, exclusive of terminals, $101,000,000 was appropriated for about 350 miles. This is a cost of nearly $300,000 per mile; in addition to this $19,000,000 was voted for terminals. (These figures, when compared with Ohio River costs, at once suggest the great advantage of utilizing rivers instead of digging artificial channels thruout.) The possible capacity of the Erie Canal, as limited by its locks, 45 feet wide by 310 feet long (available chamber) by 12 feet deep on sills, is less than a fourth of the Ohio's weirs and locks. The barge canal complete, therefore, will cost per mile nearly four times as much for less than one-fourth the carrying capacity of the improved Ohio. It has the advantage, however, of being more direct in alignment.

Continuing the comparison under this caption, a highway of thirty or forty million tons per mile yearly capacity would cost probably in excess of $150,000 per mile, while its maintenance charge would be very heavy indeed, as suggested in the next caption. An ocean route is limited as to

*House Document 492, 60th Congress, 1st Session.

capacity, cost and maintenance, only at the short terminal channels. The Great Lakes' route is limited in capacity by locks at the Soo. The possible capacity of Poe lock there, is upwards of 20,000 tons per hour in one direction, (the most unfavorable way as to time of lockage required for traffic to present itself at a lock). The possible capacity of the locks (excluding weirs or navigable passes) on the Ohio is about 12,000 tons per hour in one direction. Lockage itself in general consumes only about one minute per foot of lift, most of the time is lost in clearing in and out, this being greater for barge fleets than for lake freighters.

The capacity of smaller streams than the Ohio, such as the Scioto, were it canalized, would be less than the larger stream, but larger than the Erie Barge Canal, which is only 94 feet wide in rock, less than 100 average in earth, and 200 feet in river reaches. Smaller streams mean smaller locks, smaller channels and usually steeper slopes, necessitating more frequent lockage than is needed on larger rivers. However, in this last respect it will not do to generalize too far. For example, the Scioto from Columbus thruout 100 miles to its mouth, has a slope of only about two feet per mile, while the larger Great Miami at Dayton, has a slope of about four feet per mile for the 75 miles from Dayton to the Ohio River. (See Chart of Commercial Routes on a later page.) On the Scioto or Miami, were locks to be used, they would be about 400 feet long and one-half the width of Ohio River locks, with the same nine feet depth on sills, however, to allow the loaded barges of the latter stream to proceed upstate without breaking bulk.

As to cost per capacity of way on these smaller streams the Scioto may be used for comparison. Using moderate lifts of ten or twelve feet, twenty combined locks and dams at $250,000 apiece would be needed for the 100 miles mentioned. Probably the additional expenditure (including levees, dredging and other accessories) needed to make the reach navigable, would not exceed $5,000,000, making in all $10,000,000 for 100 miles, or $100,000 per mile for the lower river. (The writer believes this estimated cost to be excessive if the river is treated simultaneously for other benefits proportionately, but it will take careful surveys and estimates to arrive at the truth, and no such examination has yet been made.) The canalized Scioto with locks of half the capacity of Ohio River locks, thus should not exceed a cost of $100,000 per mile for the lower river. The cost from Columbus north should fall much below this amount, as explained in Chapter VIII. The capacity as limited by such locks would be about 5000 tons per hour, or about 35,000,000 tons per annum, if we allow 12 weeks per year on the average to be closed to navigation. This exceeds the estimated possible operating capacity of the Chesapeake and Ohio Northern Railroad now being built parallel to the river at an estimated

cost of $110,000 per mile from Ohio River to Columbus, with its very low grades and passing tracks at 5-mile intervals. (See Chapter VIII.)

The foregoing paragraphs under this caption, and some under the caption following, show that as to first cost per mile of way on basis of possible carrying capacity, waterways form a converging series from most expensive artificial channels (canals) excavated thruout, thru canalized small streams and larger rivers, to cheap lakeways and cheapest ocean. That is, considering waterways alone for transportation purposes only, canals are most expensive, small canalized rivers next, large canalized rivers next, lakeways next to cheapest, and ocean cheapest of all.

That traffic is not offered up to the possibilities of each route is another question which we consider in a later article on national and state policy. On no way is traffic offered up to the limit of possibilities. Traffic is not offered at such times and in such quantities to railroads as to enable them to operate at maximum yearly capacity. What we are here discussing is the advantages nature offers, whether we make use of those advantages or not. We wish to know the inherent advantages and disadvantages of all ways, whatever artificial restrictions may be laid upon natural conditions.

(8) *Maintenance of way.* This item constitutes about 20 per cent of the total operating expenses proper of railroads. By "operating expenses proper" we mean exclusive of interest on first cost, which constitutes the bulk of what is usually accounted as "fixed charges." (The latter on the average amount to about 25 per cent of the total expenditure of railways.) The 20 per cent for maintenance of way is made up of cost of keeping up rails, ties, ballast, banks, ditches, and of maintaining structures such as bridges, culverts, fences, switches, yards, stations, etc. The aggregate cost of maintaining way depends largely on the amount of traffic passing over it. For roads of moderately heavy traffic, say for 3,000,000 tons per annum over each mile, it averages from $1,200 to $1,800 per mile. This cost increases with the traffic up to $8,000 or more per mile for a traffic of about 10,000,000 tons per annum over each mile. (See Railroad Operating Costs, Volume 2, page 29, by Suffern & Sons, 1912.)

The Army Engineers estimated the annual cost of maintaining and operating the improved Ohio at $1,000,000 per annum for the 967 miles, total length of river, or at the rate of $1,035 per mile. This expense would vary very little with the amount of traffic using the river. A water track does not wear out as do rails and ties and ballast. Maintenance of structures in a waterway modernly built runs less than that on railways per dollar of first cost. In this connection, it is interesting to note, that *in the March, 1913, flood, no dam of any consequence in the State failed, whereas bridges were wrecked in nearly every part of the State* as shown on the State Highway Commissioner's map in pocket at the rear.

Maintenance of highways runs proportionately highest of all. This may readily be inferred from the fact that in New York, where experience in maintaining highways is more comprehensive than in other States, roads of very limited capacity, costing about $15,000 per mile, were costing in 1912, $1,000 or more per annum for maintenance per mile. This figure will doubtless fluctuate, due to worn-out roads being largely rebuilt. But even at $500 per mile the cost is high when compared with other ways on ton-miles per mile transported.

Maintenance figures are not yet available for the New York Barge Canal. Enough has been said, however, to show that a regulated stream ordinarily will have the advantage in cost of maintenance over rail or high way. Indeed, if a stream were effectively regulated, this would not only reduce its own maintenance cost as a transportation route, but it would also reduce maintenance charges (by reducing flood damage) of rail and highways using its valley. It would also reduce maintenance costs on railroads and highways crossing the stream valley, as suggested in the Highway Commissioner's map already referred to.

(9) *The cost of conducting transportation* on railroads is made up of a great many items in the accounting system of the Interstate Commerce Commission which are too numerous to list here. Their sum constitutes usually a little more than half of the total of all "operating expenses proper." Many of the items relate largely to passenger service. Eliminating them and other items entering into other captions than the present in order not to discriminate against railways, water routes appear to have the advantage in this item of cost per ton-mile.

The average lake freighter of about 10,000 tons burden has usually a crew of 26, consisting of one captain at $225 per month, one chief engineer at $175, one assistant engineer at $125, a second at $86, two oilers at $55, six firemen at $52.50, one first mate at $125, one second at $90, one boatswain at $80, four wheelmen at $55, one steward at $90, one second cook at $36, one porter at $30, and four deck hands at $31.50, per month. This is exclusive of subsistence which ordinarily does not exceed 50 cents per man per day.

Calculations based on the foregoing figures, on the average ton-mileage of such a vessel, during the navigable season and on a proper proportion of administration and other charges during the year, show that cost of conducting transportation on lake steamers falls both absolutely and on a percentage basis much below the cost of conducting transportation on rail per ton-mile. On Ohio River barges the cost falls below that on the Lakes. A lake freighter carrying 10,000 tons has usually about 2000 horse power installed, in order to make a speed of between 10 and 12 miles per hour, depending on the load. On Ohio River the stern wheel steamer Sprague,

which has about 2175 horse power installed, has taken downstream a load of more than 50,000 tons.

(10) *Terminal charges* for rail and waterways are difficult to compare, because both are in a stage of rapid transition in this country and are made up of a number of factors varying in different localities. We wish to know how costs of transshipping from rail to rail will compare with that from rail to water, and from one water channel to another, as for instance from Great Lakes to Erie Barge Canal, or from ocean liner to canal or river barge.

Writers often assume that there is no cost of transshipping from rail to rail, but this is not quite true. Thus, in shipping coal by rail from West Virginia to Duluth, the heavy coal trains at present in use could not proceed with their powerful engines from one terminus to the other. Different railroad divisions have different engine tonnage ratings, and their bridges will not always permit the same heavy engines to be used thruout. Solid trains, therefore, do not proceed thruout such a long haul, but would be made up anew at one or more points on the way, even if one company owned the whole route, which is not the case at present. Transfer charges, therefore, from one company to another or from one division to another of the same road, form an item of expense corresponding to transshipping costs from water to rail, or *vice versa*.

Terminal charges at ports are made up of wharfage, loading and unloading, warehouse or storage, and other costs requiring extensive analysis if fair comparisons between rail and water transfer costs are to be drawn. Wharfage in the case of public docks, would be offset by overhead and operating costs of private docks.

The land needed for water terminals is usually cheaper than that needed for rail terminals, but the construction costs needed for the former are usually more extensive than those needed for rail terminals of the same tonnage capacity. Some figures suited to Ohio conditions, are given in the following example:

One road in central Ohio (a heavy coal hauler extending from the coal fields to the Lakes) has recently installed interchange and classification yards for its coal traffic in the central part of the State, and a modern water terminal with accessories for transshipping coal from rail to boats, on Lake Erie. The interchange yards (about 11 miles of track) cost about $100 per car of storage capacity, or assuming each car to hold 50 tons, this is a first cost of $2 per ton capacity of yard.

Its coaling dock and accessories at Lake Erie cost about $400,000, consisting of two car-unloaders at $91,000 apiece, a power house at $80,000, with the balance for yards and docks not separated in cost data available.

The slip between the two machines will accommodate four 10,000-ton lake freighters at a time, making a cost of $10 per ton of storage capacity, versus $2 for the railroad yards.

But again, (as in the case of motive power, caption number 6 preceding) in addition to interest on the above investment, operating costs enter in the consideration, and unfortunately here we have not data complete enough to make fair comparison. The following considerations, however, throw some light on the question.

Switching charges for cars within the smallest switching zones in cities run usually about $5 per car. Assuming every car to average 50 tons capacity, and assuming the cost of making up trains in interchange yards at one-tenth this cost, the result is one cent per ton for interchange or transfer from rail to rail. This figure is undoubtedly low when every item of cost is included.

At the lake dock above mentioned, the cost of transferring annually upwards of 2,000,000 tons of coal from rail to boat will run about 2 cents per ton, figuring in the operating expense, the labor, maintenance, depreciation and interest on investment. At a smaller older dock, for which figures are available, the cost has run for two years nearly 4 cents. Near the latter coal dock, where 400,000 tons of iron ore are handled annually, the cost has run nearly 13 cents per ton, due to handling much of the ore twice, (from boat to stock pile and from stock pile to car). At the better ports, such as Ashtabula and Conneaut, where 6,000,000 tons or more of ore and coal are handled annually, the figure runs far below the last one given.

Warehouse, storage, or stock pile charges can not be charged wholly to waterways, for, railroads benefit as much from them as do water carriers, especially at ocean harbors, and largely also at lake and river ports. Enough has been said, altho our discussion is entirely too brief, to show that with rapidly improving transferring facilities and gradually increasing traffic, transshipping costs should not exceed 5 cents per ton at a modern terminal with moderate traffic; and not all of this should be charged to the water carrier.

Conclusions as to Advantages. A volume could easily be written on each of the foregoing ten captions on advantages. Enough has been said, however, to account for the larger part of the great discrepancy in lake and rail rates shown in Figure 11 and in Table IV. If we compare ton-mile costs, water transportation has much the greater advantage in all of the ten essentials, except the last. We have assumed modern ways of each kind thruout, because that is what discussion will have to be based upon to foresee the future. While rail shipments at present are not made in large quantities thru such long distances as are water cargoes, we may

assume that such will become the case in the future and charge transshipping costs against water.

Transshipping charges at 5 cents per ton charged against lake haulage, amounts to only .06 of a mill per ton-mile for the average distance of 831 miles, which each ton was hauled on the Lakes in 1912.

Also interest on first cost, and cost of maintenance of way, should be charged against lake traffic to make fair comparison. From 1883, to November, 1912, $131,557,941.20 was expended by the United States on harbors, locks, and channels of the lakes, according to S. M. Sparkman, chairman of the Rivers and Harbors Committee in Congress, in *National Waterways* for November, 1912. While this does not include the money spent prior to 1883—a relatively small amount—neither do the tonnage tables (published by the Army Engineers in charge of the improvements of the Great Lakes) include all tonnage from harbor to harbor. The freight passing the Soo in 1912, was 71,472,676 tons, with an averaged haul of 831 miles. If interest on the above expenditure be prorated to this tonnage, the result is only one-tenth of a mill per ton-mile.

Maintenance expenditures are included in the above $131,557,941.20 total expenditures during the 29 years. They are not available as a separate item, but any reasonable proportion per annum divided by the total mileage will not bring combined interest and maintenance charges together up to two-tenths of a mill.

The three foregoing charges for cost of transshipping, interest on investment, and cost of maintenance of way scarcely exceed 0.2 mill per ton-mile all told. This amount should be added to the lake rates in Figure 11 and Table IV to make direct comparison. When it is done, however, it affects them only slightly. Figure 11 is, therefore, a substantially correct picture of the remarkable efficiency of the Great Lakes as an instrument of transportation. We conclude that, in general, *lake transportation is at least 6 times cheaper than that by rail.*

Canalized Rivers and Canals

How do river transportation costs compare with lake rate? We have already anticipated some items of cost of river transportation in our discussion of lake rates. Army Engineers state in their report on Ohio River, already referred to, that barge transportation on this river affords one of the cheapest modes of transportation in the world. Moulton says at page 342, in *Waterways versus Railways* "It should be borne in mind that the cheapest method of handling water traffic is in barges."

These statements must not be accepted as applying to rivers and canals indiscriminately. There are inherent disadvantages in water transportation which need to be listed and examined, more especially as

they apply with greater force to inland waterways than they do to the Great Lakes or ocean. It is with inland navigation on canalized rivers that we are here chiefly concerned.

Disadvantages

Disadvantages of water transportation: (1) Waterways cannot reach interior points as railways and highways can, and hence involve transshipment to the latter. (2) River and canal routes are usually longer between termini than railroads between the same points. (3) Due to slow transit water-borne traffic is usually limited to low-grade or non-perishable goods. (4) Due to ice, waterways in northern latitudes cannot operate thruout the year. (5) Other disadvantages, listed by Peyton in *The American Transportation Problem*, are changing banks, shifting sand bars, danger from snags and logs, fogs, windstorms and danger from ice.

(5) Let us consider the above five topics in reverse order, and as obtaining in Ohio and vicinity. Streams in this vicinity *change their banks* very slowly, even altho none of our streams has a regulated flow, or a flow even approaching regulation. Floods of the past have washed their banks to practically stable conditions. They are, however, subject to shifting sand and gravel bars, especially opposite the mouths of unregulated tributaries. For the improved Ohio River, Army Engineers have considered this problem carefully and their estimate for maintenance, quoted in a previous paragraph, includes dredging such bars. They do not propose to regulate the main river nor its tributaries by reservoirs, but estimate the cost of maintaining the canalized stream upon the basis of cost of dredging already experienced in the open river.

Omitting danger from ice, considered separately below, it would seem that the danger from snags, fogs, and windstorms on a modern improved river may be fairly offset by dangers incident to conducting other forms of traffic. Thus railroads have derailments due to chipped flanges and broken tires and axles. They have collisions due to misplaced switches and other operating mistakes. They have collisions due to fogs and curves, as rivers may have. As to obstruction of right-of-way, it would appear that those of railroads are subject to as much chance of accident as are water routes, so long as the former are not respected as private property in this country as they ought to be. Washouts cause accidents on railways which might be offset aganist unforeseen obstructions under water. It seems hardly worth while trying to make out a case in favor of either way from the standpoint of danger.

(4) *Ice dangers* are usually minimized in rivers by closing navigation and providing ice harbors. Winter weather brings its troubles to railways

also. Broken rails increase accidents, while other contingencies are raised by sleet and snow. Winter weather, however, in northern latitudes at least, brings out an inherent disadvantage of water routes; they can not operate the year thru. Thus seven months (May 1st to December 1st) is an average season on the Great Lakes, due to ice in the latitude of Lake Superior. On Ohio River not more than ten weeks on the average would be lost. On a north and south waterway across the State, the closed season might average about two weeks longer, at the latitude of Lake Erie. These periods have been taken into account already in discussing advantages. We will assume them for subsequent purposes also.

(3) As *to time of transit* the most economical speed for river barges in still water of ample depth is considered to be five and one-quarter miles per hour by the U. S. Towboat Board in their report of 1914. Fleets of coal barges at present move from Pittsburgh to New Orleans in 16 or 18 days, when navigable depths are available. This is at a rate of about 110 or 120 miles a day or at 5 miles per hour average maximum downstream. When compared with freight car movements per day, this seems high. It should be said, however, that shipments have often been made quicker by river than by rail, altho normally rail shipment should be speedier. In restricted channels, like canals, barge movement is at slower speed, it being estimated by Elnathan Sweet in the 1901 report on New York Barge Canal, that for its standard sections speeds of more than 3 miles per hour were economically inadvisable for loaded boats.

From foregoing considerations it is evident that water borne traffic may, at many places, include perishable goods. It does often include such goods on the Lakes. However, its special field is low-grade freight, or freight requiring very low rates to extend local markets. Thus the Ohio, when improved, in addition to handling low-grade stuff, will almost certainly greatly extend the markets of the steel and clay-ware factories of the Ohio River basin. The time will come when we will need all available transportation methods developed to their highest efficiency. How water routes may then affect the situation, is concretely illustrated in a later paragraph on shipments of low-grade products from our West Coast.

(2) *River and canal routes are usually longer between termini* than rail routes between the same points. From Pittsburgh to St. Louis, for example, by rail is 613 miles, while by river it is 1149 miles, (967 from Pittsburgh to Cairo and 182 miles from Cairo up the Mississippi to St. Louis). From Pittsburgh to New Orleans at present, by rail, is 1147 miles, shortest way. By river it is 1927 miles, (967 from Pittsburgh to Cairo and 960 from Cairo to New Orleans). These are fair samples, altho many railroads parallel rivers and are equally long. We may assume, for general purposes, that inland routes average about 50 per cent longer than rail routes be-

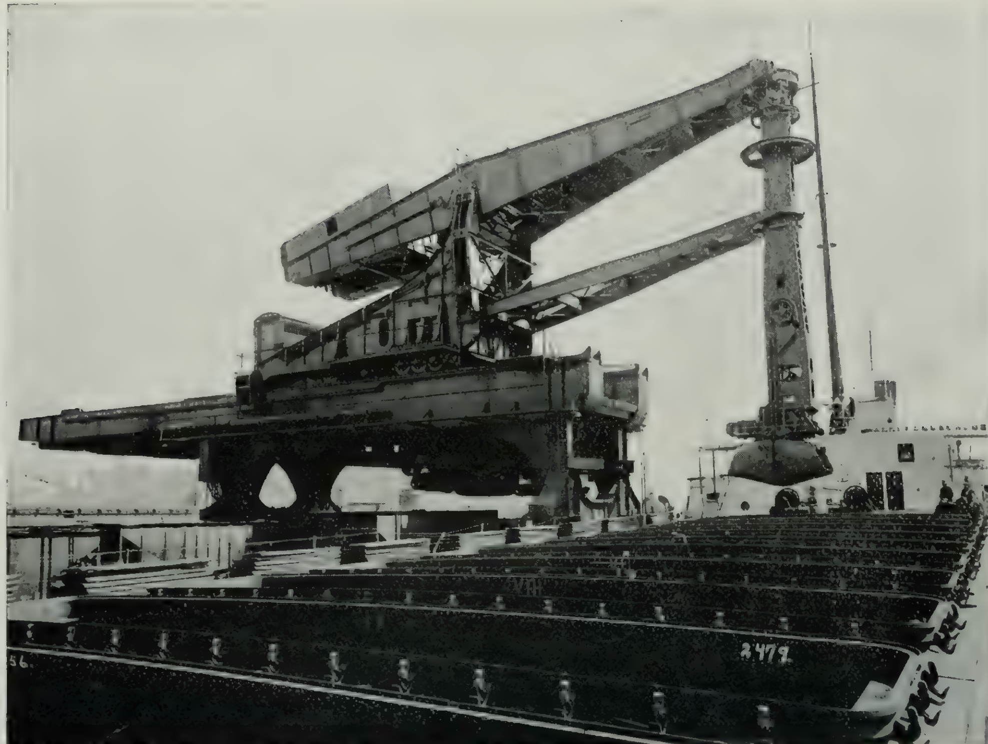
tween the same termini. The ton-mile river rate, then, must in general on this score be increased 50 per cent for true comparison with rail costs.

(1) Waterways can not reach interior points as rail and highways can. *Transshipping* charges must, therefore, be added to water rates. The subject of transshipping is a large one, as will be evident upon examining the reports of the New York Barge Canal Terminal Commission, and of the United States Towboat Board, and other publications too numerous to mention here. Transshipping facilities are in a stage of transition the country over. We are far behind the foremost countries of Europe in the attention we have given to transshipping from rail to water.

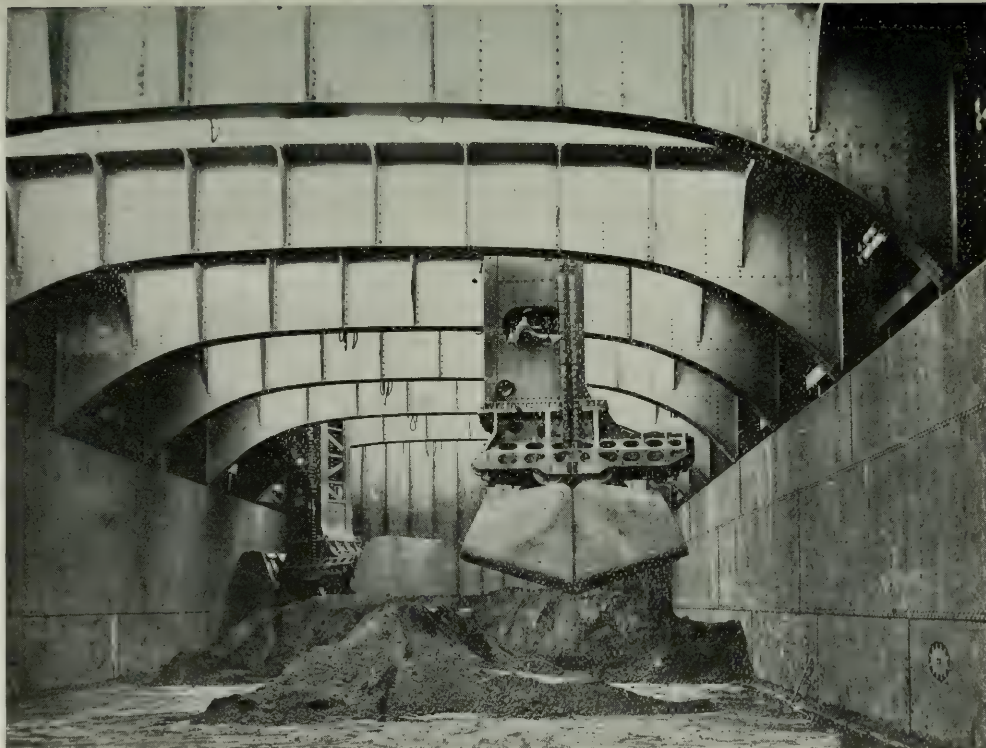
The facilities for transshipping coal and ore at Lake Erie ports, however, are an exception to the last statement. The most striking visual exhibition in the world, of improvements in transshipping, is probably that at Ashtabula, Ohio. Here improvement has succeeded improvement, from the primitive "whirley" of 20 or 25 years ago to the modern Hulett ore unloader of today, so rapidly that it has not paid to dismantle the discarded machinery, and five kinds of unloading machinery stand along the river bank for a mile or so, forming a veritable museum of the art.

Nearly everyone is familiar with the coal unloading machinery now in use at all the main Lake Erie ports. These machines pick up a coal car, no matter what its size, and by turning it up-side-down, empty the contents into the boats at an average speed of about two and one-half minutes per car, when cars are available. For example, one of the McMyler unloaders at Ashtabula, has unloaded 227 cars from 6.30 A. M. to 4 P. M. The cost of thus loading coal into lake vessels has run under four cents per ton at one smaller port for which the writer has figures. This figure includes interest on cost of, upkeep, and operation of unloading plant and yards connected therewith, for about 1,500,000 tons handled annually.

For removing ore from lake vessels onto cars or stock piles the expense runs about four cents per ton with Gantry cranes. With later forms of ore handlers, such as the Hoover-Mason or more recent Hulett electric unloaders, the cost falls much below the last figure named, where the traffic to be handled is large. The latter machine is a marvel of modern engineering, and is probably the finest in the world for cheap handling of low-grade bulk freight. As shown in accompanying cuts it is operated from a compartment immediately above the shovel (or scoop), which can pick up 12 tons of ore at a time. The operator, housed immediately above the shovel as shown in the pictures, can open and close the scoop, rotate it about a vertical axis, raise it vertically up to clear the vessel's sides, and move it horizontally back and forth to drop the load into hoppers feeding into the freight cars shown in one of the pictures. In addition, the machine automatically weighs the load delivered to each car.



Hulett Unloader, General View
Courtesy of *National Waterways*



Hulett Unloader, Scoop Inside Vessel
Courtesy of *National Waterways*

This machine, therefore, obviates practically all trimming toward the hatches in unloading. Since modern lake freighters have decks practically covered with hatches, virtually all trimming away from hatches is also avoided in loading them with coal or ore. How great an advance these methods are, over those in use 20 years ago, may be realized from the following quotation from the Chittenden report, page 19:

> "At the terminal of boat lines the cost of unloading coal is two and one-half cents per ton for 'trimming' toward the hatchway, and fifteen cents per ton hoisting out, making seventeen and one-half cents per ton, and in loading the cost of placing on board and trimming are the same, making the cost of shifting from one boat to another thirty-five cents per ton."

At New Orleans coal is now shifted from barge to ocean steamer at less than five cents per ton, it is stated.

The developments in transshipping have been dwelt on here for a double purpose. We wish to know something of transshipping costs, and also our example well illustrates how arguments based on past experience are based on shifting grounds. In the present paper we wish to consider only modern ways and equipment of each kind, for that is what we will ultimately come to. While the above examples show we lead the world in transshipping bulk freight, it is true that at present we are far behind Europe in the handling of package freight from waterways to railways. When our waterways are suitably developed with proper terminals, we shall undoubtedly experience great improvement in package freight handling. The banana unloaders recently installed by the United Fruit Company at New Orleans, point the direction in which we are tending.

Conclusions as to disadvantages. From the foregoing discussion the chief disadvantages of water routes are seen to be longer length of way, and failure to reach interior points. Thus transshipping costs must be added to water rates, when their effect is considered on business which does not lie immediately on the water front. These disadvantages almost vanish for both interior and other points when the distance hauled is great and the freight is of such grade and quantity that modern transshipping machinery may be used. In this connection interior points should notice that one of the most far-reaching laws yet passed by Congress was the Mann-Elkins Act of 1910, which gives the government the power of compelling rail and water carriers to prorate rates equitably, upon demand by the water carrier. This law, with forthcoming improvements in it, will eventually prevent discrimination against the natural advantages enjoyed by a given locality.

The good effects of such legislation will require some time for full fruition, but it can not be doubted that it will ultimately enable interior

points to realize fully upon their natural advantages. The slow but gradual reduction of rates toward equity on railroads is attested in late years by the remarkable growth of such inland cities as Indianapolis, Columbus, Atlanta, and Birmingham. Nevertheless, the natural advantages of water transportation is attested by the still greater growth of cities on adequate waterways, and by the efforts of some cities to make themselves ports in the face of great difficulties. American instances of the latter are Los Angeles and Houston. The most striking example in the world is the city of Hamburg in Germany. This City has provided depth for the greatest ocean liners to come some 60 miles up the Elbe, and had become before the war the second seaport of the world.

Canalized Rivers Versus Canals. The National Waterways Commission unanimously concluded that canals are in general inadvisable except for short stretches connecting natural channels. The Commission pointed out that rivers furnish channel routes already largely excavated, while canals must be excavated thruout. River banks, thru natural causes, are better prepared to withstand wash than are canal banks. Canals usually occupy lands valuable for other purposes, (the whole right of way usually having to be purchased) while rivers do not. Rivers naturally furnish drainage while canals usually obstruct it.

The above conclusion the writer believes to be sound. The circumstances must be unusual to justify the construction of a long artificial channel. The proposed barge canal from Pittsburgh to Lake Erie (shown on the water map of Ohio in pocket) is probably an instance where transportation benefits would justify constructing the fifty miles or so of wholly artificial channel. Whether transportation alone will justify the construction of 345 miles of Erie Barge Canal in New York is problematical. It certainly does not seem to offer the economic opportunity that the improvement of some streams in Ohio does, as will be shown later.

The two foregoing paragraphs emphasize the statement made under the caption Stream Regulation at the beginning of this bulletin; a river improved for navigation may at the same time be treated for developing power, for furnishing water supplies, for diluting wastes, and for mitigating floods. Not so with canals usually. They may serve transportation, serve for irrigation, or for power development, or for other purposes, but their function is generally limited to one and only one purpose.

Conclusions as to River Transportation Costs

Canalized rivers then being assumed we conclude the transportation costs on the canalized Ohio may be as follows:

On the Ohio River we assume that 10,000,000 tons traffic will be developed after completion of the improvement. This is one tenth of the

possible capacity of the locks alone, and is exclusive of the capacity of the navigable passes which now take care of about 9,000,000 tons of traffic. We assume that the average haul of the 10,000,000 tons developed will be about two-thirds the length of river, or about 600 miles. That is, that the developed ton-mileage will be six billion ton-miles. Prorating operating and maintenance of way cost of $1,035 per mile, and interest at 4 per cent on $77,600 first cost per mile (equals $3,104), we get a cost of 0.67 mills per ton-mile for these two items.

The cost of operating the equipment (including wages, upkeep, depreciation, interest on investment, and profit) should not exceed 0.4 mills per ton-mile. We believe this, because actual charges on coal barged from Pittsburgh to New Orleans has run as low as one-third of a mill per ton per mile, and this charge has included the cost of bringing the barges back empty all the way. Increasing return or upstream cargoes will undoubtedly be hauled on the river when improved.

Terminal charges we will assume to be charged entirely against the waterway, altho as has already been stated, railways profit from river ports and should bear a portion of such transfer costs. Charging transfer costs of 5 cents per ton against the river traffic for an average haul of about 600 miles, the result is less than one-tenth of a mill.

The total of all items preceding, under the assumptions made, is 1.15 mills per ton-mile. To compare this with rail charges, we must allow for longer length of way, and assuming the water haul to be in general 50 per cent longer than rail between the same terminal, the result then is 1.73 mills per ton-mile.

This, we believe, to be a fair measure of the value of improved Ohio River as a transporting instrument. Should the amount of traffic increase more than one-tenth of its possible capacity, (and one-tenth is a low figure) the efficiency of the improved river will be much more pronounced. It makes clear the fact that our transportation facilities have not yet reached the high degree of efficiency that they are destined to reach. If it be objected that 10,000,000 tons traffic is too high a figure to assume, it may be answered that no railroad now building contemplates handling as little traffic as one-tenth its possible carrying capacity.

Conditions as to transportation, especially on water have not, therefore, reached normal in this country. Why this is so, is made clearer in the next chapter on Broader Aspects of Water Transportation.

CHAPTER V

BROADER ASPECTS OF WATER TRANSPORTATION

We have attempted to discuss preceding transportation questions on a scientific basis, with a view to foreseeing future possibilities, rather than to indulge in or invite interminable discussion of what has happened in the past. To base discussion on the latter is to base argument on shifting grounds, for, the development of our country in the last fifty years has been amazingly rapid, and it is now and will doubtless be for the next fifty years in a similar stage of rapid transition, as illustrated already in the one detail of transshipping.

To compare efficiency of transportation methods on the basis of lowest rates that have been charged is misleading, for, the peculiarities of of rate-making as it has been (and still is in exceptional or insolated instances) furnishes too many misleading examples. It would be as logical to require all railroads to reduce their passenger fares uniformily to the lowest excursion rates they occasionally make, as to assume that the lowest freight rates ever charged are the correct measure of transportation efficiency. For example, a carrier to avoid returning empty from direction of heaviest traffic may charge a rate below real cost of service. Instances of this can be cited for both rail and water carriers, the cheapest rates in the world being sometimes made by ocean vessels taking cargo for ballast.

Likewise it is almost as futile to base comparisons in this country upon the experience of the more advanced countries of Europe. Volumes have been written attempting deductions in this way, with usually uncertain and unsatisfactory results. We may profit from the experience of the older countries of Europe by adopting the best devices they have developed, more especially in the way of planning and managing combined rail and water terminals; but geographic, commercial, and political conditions are so greatly different in Europe from those in America that the former affords an uncertain guide in the larger questions of transportation here.

The writer has wished to avoid politics in writing this paper, at least in its cheapest meaning. Transportation questions in our country are apt to be made the subject of party issue, along with the tariff, yet nothing would seem clearer than that both these questions should be kept free from politics. Both are clearly matters of business and should be handled as our railroad questions are, by commissions of the best talent to be had. Who would favor abolishing our Interstate Commerce Commission, and throwing all questions pertaining to railroad transportation back upon the floor of Congress to be juggled however honestly by that body? Because we thus still largely handle questions of water transportation, it has seemed advisable to say a few words on national and state policy. It is necessary also, because both policies directly touch the subject of this paper.

National Policy

Rightly or wrongly (the writer believes rightly) our National Government has extended a policy of help, in one form or another and under one name or another, to all our great activities except one, which should have been helped. With a view to developing each activity to a healthy maturity, Congress has extended a helping hand to internal industries, to railroads, to inland waterways, and to coastwise shipping. The one exception is our shipping interests engaged in foreign trade. This has been suffered to decline almost to the point of perishing without national help.

Considering the five in reverse order, it would seem that much help could have been extended to our vessels in the foreign trade, if, in executing the treaties prior to building the Panama Canal, Congress had left itself free to charge such tolls as it saw fit on vessels passing thru the Isthmus. For example, without entirely remitting tolls on American vessels, a reduction of fifty cents per ton to such a vessel of say 10,000 tons burden would amount to $5,000 per trip to apply toward paying the necessary higher wages of American seamen, or toward higher costs of American ships over those built in foreign yards. The opportunity has seemingly been lost, and other means may have to be used to encourage our ships to carry our own and foreign goods to foreign ports, or the present practice be continued of allowing the great bulk of our ocean traffic to be carried in foreign bottoms. It would seem that we did not wisely solve the first of the five great problems at Panama listed on page 29.

Coastwise shipping has received help in the form of laws, which contain such heavy restrictions that foreign vessels are excluded from this class of traffic. This policy has been in force practically from the beginning of such commerce, and has been extended to cover Alaska, Porto Rico, and the Hawaiian Islands. Even on the Great Lakes, foreign (Canadian) vessels may not carry passengers or freight from port to port on the American side. This restrictive legislation has resulted in increasing the tonnage of the American coastwise fleet to over 6,000,000 tons burden. In comparison the tonnage of all vessels of the great Hamburg-American line is slightly over 1,000,000 tons.

From the appropriations for rivers and harbors, $346,812,362 in all had been allotted to rivers up to January 1st, 1911.* The total to date will not exceed $400,000,000. (Compare these figures with the amount of aid advanced to railroads by various governmental agencies as noted in next paragraph.) In disposing of the public domain Congress has excluded from sale the lands underneath what the Land Office surveyors returned as "navigable stream." This term, in the early days when the lands were first surveyed, included many streams that are now not considered navigable except for the lightest kind of craft (canoes in some instances). (See later

*Van Ornum, The Regulation of Rivers, page 3.

comment on Ohio streams in this connexion.) To promote cheap transportation Congress has expended the foregoing sum in disconnected improvements upon these streams, and upon others lying in areas that were never public lands, but over which the Government has exercised jurisdiction under what is known as the interstate commerce clause of the constitution. Virtually all cost of stream improvement for transportation purposes at this time is therefore borne by the National Government on those streams which carry interstate commerce, or which by its own definition are "navigable" as already noted.

While it is true that at present railroads pay their own costs of construction and maintenance and also pay taxes as contrasted with waterways, it is also true that during the period when they were developing their modern efficiency, a virtual policy of help or protection was extended to them in the way of grants or subsides by various national, state, and smaller governmental agencies. The total amount thus granted, is not know exactly but from Appendix C following we may judge it to be much more than the amount that has thus far been expended by the public on inland waterways. This was undoubtedly in the main money wisely spent.

By means of a protective tariff on imports, a helping hand has been extended to our manufacturing industries, until we have seen some of them grow to a size and efficiency unequaled elsewhere in the world. This has caused some fear that immense corporations have gotten beyond the control of the Government. To allay such fear it is only necessary to review the recent history of the greatest of them all, those corporations involving the investment of the greatest amount of private capital—our railways—to see that the Government is abundantly able to control its creatures. The law of economy inevitably leads gradually to larger and larger combinations with more and more efficient organization. The problem is not how to break up or prevent such combinations, but how to secure an equitable distribution of their benefits. In this we are gradually making progress. These remarks would not be made here, were it not for the unworthy arguments sometimes seriously advanced, such as, for example, that a little more than half of the Great Lakes tonnage is carried by and for the United States Steel Corporation, and hence that the benefits of the Great Lakes traffic to the public are reduced by that amount.

So much for what has happened in the past, in the five great fields of industry above briefly touched upon. We wish to know what will happen in the future, in order to act wisely in the present. *To the writer it seems proper that we should develop our inland waterways into efficient instruments of transportation when this can be done, and after sufficient traffic has been developed on them, charge tolls for cost of operation and maintenance,* and of interest on construction. Such appears to be the program at Panama, and

such appears to have been the history (when stripped of details) of our railroads during the eighty-five years of their existence in this country. All three instruments just mentioned serve the same great cause, and for this reason it is probable that we are drifting toward government ownership of railroads. It is to be hoped, however, that such ownership will not come until we have made sufficient progress in the art of government to handle them with intelligence and honesty. This seems likely to require fifty or a hundred years yet if one may judge from the following brief review of the government's management of inland waterways.

The immediate work of designing and constructing improvements on our inland rivers for navigation has from the beginning been under as able and honest a staff as the country affords, namely the corps of engineers of the United States Army. But unfortunately Congress has itself attempted to decide, often without adequate reference, the more important questions. The sad feature is that as a result there has been no adequate coordination of the work. A table of the various sizes of locks built in different parts of the country, even in different portions of the same river system, shows the confusion that has prevailed. A lock limits the size of craft using the way, and different sized locks would correspond somewhat with railways of different gage. Of course the rapid developments in transportation during the past fifty years naturally gave rise to confusion. It has been impossible to keep waterways, as well as other ways, up with desirable improvement of vehicle. The rapid increase in size and efficiency of ocean going vessels in recent years well illustrates the period of rapid transition. Then too, it is of course economically impossible to use locks of uniform size thruout a given river system from mouth to headwaters. These two factors constituted an unavoidable portion of the lack of correlation, but the avoidable part was directly due to absence of a general policy on the part of Congress, illustrated still more strikingly in the following paragraph.

Over-enthusiastic or misguided congressmen have in the past secured the improvement of isolated stretches of river. This would correspond to building branch railways and leaving the main line untouched or incomplete. It is evident that main waterways should be completed first. To do the reverse is to cause confusion not only in national work but also in improvements undertaken by smaller political units as well, as is illustrated specifically on page 70 in discussing state policy. In view of its administration of inland waterways and its handling of our merchant marine engaged in foreign trade, one is glad that our National Government has not had direct charge of developing our railways in the past.

Some progress has, however, recently been made by Congress toward a definite policy for inland waters. In 1902, it was decided that thereafter no river improvements should be undertaken by the Government until

such project had received approval by an advisory board of engineers on rivers and harbors and the chief of engineers of the army. Thus was constituted for handling waterways a competent board paralleling the Interstate Commerce Commission for railroads. The provision was wise and should be adhered to, rather than be made the subject of political attack as has recently been done.

In 1910, important provisions affecting general transportation were made in the Mann-Elkins Act already referred to. When the act to regulate interstate commerce was passed in 1887, boat lines were intentionally exempted from its scope. The Mann-Elkins Act of 1910, provided that the railroads and boat lines should prorate charges under direction of the Interstate Commerce Commission, if the boat line so desired. Also, it was provided that if a railroad in competition with a waterway, lowered its rate, it might not be raised again without consent of the Commission. This will prevent railroads from smothering competing waterways by temporary reductions of rates, as has happened in some instances in the past.

Improvements yet remaining to be made, as recommended by the National Waterways Commission, are that power be granted the Interstate Commerce Commission to compel physical connexion and joint rates to be made between rail and water lines, to compel less than local rail rates to sea, lake, and river ports where such traffic is to be exchanged with water carriers at those ports for thru haul, and to compel thru bills of lading to be issued whether the traffic travels all rail, all water, or water and rail. Unless such powers are granted to the latter commission, the National Waterways Commission believed "it possible for the railways to effectually control or crush out water competition thru their ownership and control of boat lines."

The most important portion of progress in inland water transportation, in both legislation and construction, *therefore, remains yet to be made.* In the way of better laws, boat lines should be brought under regulation of the Interstate Commerce Commission as the railways now are. In the way of construction, aside from the very serious defect of a lack of dependable adequate depth in main rivers, the most serious defect of all is the lack of joint rail and water terminals. In this respect we are far behind Europe.

Thus we are slowly progressing from the old primitive methods of handling waterways in River and Harbor bills which were spasmodic, without definite policy, and subject to revision on the floor of Congress at the whim of the members, toward a correlation of our great transportation facilities which will secure to the public a maximum of economic advantage. It is to be hoped that such progress will be made decently and in order. It would seem, in order to avail ourselves of the great advantage of complete organization, that no corporation should be forbidden to use any or

all ways of transportation, for cooperation not antagonism must be the ultimate outcome of our transportation problems. If proper regulatory power is given the Interstate Commerce Commission over water as well as rail carriers, the question of ownership or direction of transportation lines becomes of less importance.

If our previous exposition of the inherent advantages of water transportation over all other ways is correct, and if our forecast of the future of waterways and national policy is sound, and if we shall develop foreign trade, which the writer believes will happen, then some interesting results follow directly affecting Mississippi Valley States, Ohio with the others. This is the great producing region of the United States. The opening of the Panama Canal should greatly increase trade with our own West Coast, and should put us in command of trade with the west coast of South America, if not of a large portion of increasing trade with the Orient. If this is not so, why did we build the Canal?

The map of transportation routes of the world, in pocket at the rear, has been drawn to show the effect on vessel tracks, and to suggest future traffic possibilities afforded by the Canal. It is certain to greatly increase trade with our own West Coast, and the effect on trade with the west coast of South America may be judged from the fact that in the past to avoid transshipping at both ends of the Isthmus much traffic passed around the Horn. Vessels thus sailing up the east coast of South America are practically as near to great European ports as to principal American ones. (See distances on the map from Pernambuco to New Orleans, New York and London.) The Canal puts this traffic virtually at our doors.

The map is also an index of trade possibilities of the Mississippi Valley with other regions of the world. The railway system of a country may be taken as an index of its development. While the scale of the map is too small to show accurately all railroads in regions thickly supplied, they have been carefully drawn for those countries now undergoing development where railways are scarce. Who shall say that China within the present century shall not awaken to modern civilization, and if it does, what region is better able to supply materials of development than the Mississippi Valley? New Orleans has already become the second seaport of our country. It will be interesting to watch developments on the Gulf within the next decade or two.

What inland water transportation may be fifty or a hundred years hence in connexion with or independently of the development of our foreign trade is a most interesting speculation. A remarkable geographical situation should be pointed out in this connexion. In contrast to our Pacific coast our Atlantic is practically tideless. All the way from Colon at Panama up around the Gulf of Mexico along Florida to Hatteras the total fluctuation is only two or three feet. From New York to Maine it is only

six or seven feet at most. This great advantage permits ships to receive or discharge cargo without such expensive dredging of channels, tidal basins or locks. The expenditures for these facilities along the Atlantic ports of Europe have been enormous. (The range of the tide at Havre is about 28 feet; at Liverpool 26 feet; at London (Tilbury) 17 feet.)

Coupled with the great advantage of a practically tideless coast, nature has endowed our Atlantic and Gulf seaboards (again in contrast to our Pacifice coast-line) with many natural harbors, and with *a third remarkable feature not elsewhere paralleled to such extent in the world.* This third feature in an inland channel paralleling gulf and ocean from Virginia around Florida to New Orleans past Galveston to the Mexican border. Large scale maps* show this striking situation which is shown approximately on the small map herewith. (Figure 12.) The natural channel is not continuous thruout, but, only inexpensive short connecting stretches would require to be excavated thru soft material lying very close to sea level, to make barge transportation feasible thruout. Such an inland channel would be free from ocean waves, rendering available the cheapest form of barge transportation. It would connect Atlantic harbors with those of the Gulf, and connect both with the inland waters of the Mississippi Valley States at New Orleans.

Portions of this route, which has been extended by proposed projects from Norfolk to New England, are now under construction. If the increase in population, and industry of our country during the past century is any guide to the next, may we not before the year 2000 A. D. see a populous Atlantic sea-board connected with the Mississippi Valley States by what appears to be the cheapest form of transportation nature can afford —barge transportation on ice-free channels of still water already largely excavated without the aid of man? A prophet, it must be admitted, has a difficult job. For example, Henry Clay in 1849, opposed as a chimera the plan to make a waterway at the Soo, where now passes the greatest tonnage of any waterway in the world.

Summary. All foregoing comparisons between road, rail, and river relate to transportation, but with that the analogy between water and other ways ceases. Roads and railroads are good for transportation alone. Regulated rivers are good for numerous purposes. Even a barge canal as proposed in the preceding paragraph may serve the purpose of drainage of lowlands and marshes in some instances, as is the case in Louisiana where portions of it are now constructed.

This phase of national policy—improving inland waters for all benefits, instead of for transportation alone—has just begun to receive attention from Congress during the past few years, as evidenced by the

*See special reports of Army Engineers.

italicized statement on page 35 of this paper (from the final Report of the National Waterways Commission in 1912), and by such recent bills in Congress as the Ransdell-Humphrey Bill, the Stirling Resolution, and the Newlands Bill of 1913. Whether wise in their details or not, these documents point the direction in which we are moving, and since the last one named is the most comprehensive of the three, we quote its general purposes.

The bill proposes an expenditure of $50,000,000 per annum for ten years for the regulation of streams (aside from the channel improvements made under River and Harbor Bills) for purposes of controlling floods, for irrigation, for reclaiming swamp lands, for furnishing domestic, industrial and municipal water supplies, for bettering sanitary conditions of streams, for developing water power, for diminishing soil erosion, for promoting forestry, and for improving navigation. It provides for the expenditure of funds by the National Government in cooperation with states, municipalities, districts, counties, towns, and other local agencies and organizations, all under the supervision of a national board, which has the final approval of the plans. (See Section 10 of the bill reported by Senator Newlands on March 3, 1913, to the 62nd Congress, 1st Session.)

It will take time to work out wisely the details of such a broad scheme. However, its general intent to improve streams for all purposes instead of one is to be commended, as is the feature of cooperation between national, state, and lesser political communities. Such cooperation is undoubtedly wise, and will come to pass more and more. If the National Government has cooperated as it has with States in their educational matters, in topographic surveys, military affairs, in the work of road building, and in other activities too numerous to mention, why should it not cooperate with them in reasonable degree in stream regulation? Streams ramify from one State into another until they touch the interests not only of one but of others and the nation at large. To determine the relative amount of work to be done by each unit interested is a problem requiring most thoughtful consideration in each case, but that an encouraging and equitable interest in stream regulation will ultimately be taken by the National Government can not be doubted. The part taken by the National Government in stream regulation in the great reclamation projects of the West, all begun since the year 1900, is an earnest of greater Federal interest in our nonnavigable streams in the future.

This chapter and accompanying ones make it clear why private parties or corporations can not as a rule engage with profit in stream regulation projects on an extensive scale. The benefits ramify so extensively in all directions that only political subdivisions can undertake such works with profit, because they alone can collect revenues resulting from all such benefits in the form of taxes on increased property values. This is the

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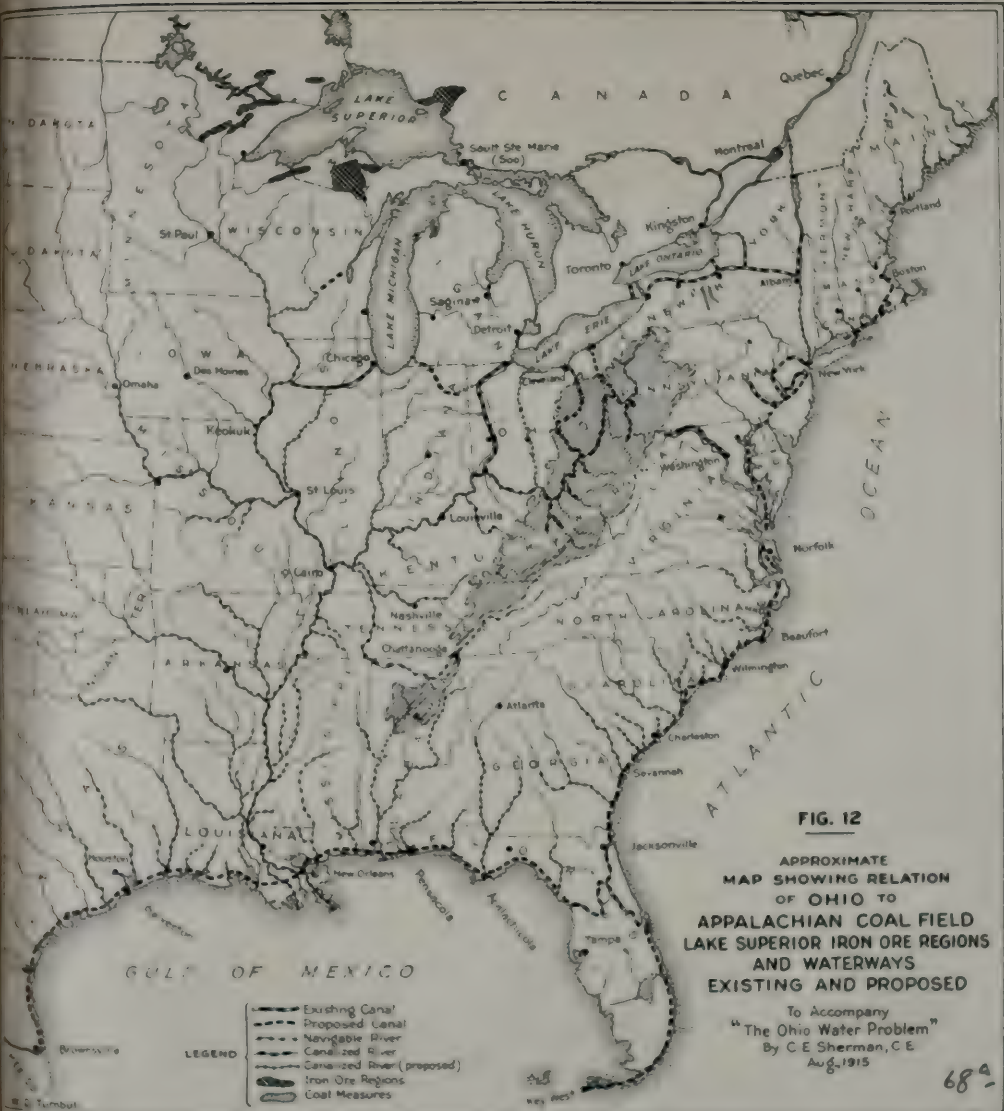


FIG. 12

APPROXIMATE
MAP SHOWING RELATION
OF OHIO TO
APPALACHIAN COAL FIELD
LAKE SUPERIOR IRON ORE REGIONS
AND WATERWAYS
EXISTING AND PROPOSED

To Accompany
"The Ohio Water Problem"
By C E Sherman, C E
Aug. 1915

answer to those who ask why does not private capital engage extensively in waterway improvements if water transportation is so cheap.

If transportation alone were benefited, private capital could so engage. The Cape Cod Canal is an instance of this. If water power alone were secured, private capital might realize upon all the benefit it created; there are many instances of this in the country. But in general an economically sound stream regulation project will produce so many and such widely distributed benefits that private capital can not collect revenue from them all, nor from any considerable portion. A political subdivision or a community then becomes the proper agency. This becomes clearer as the succeeding chapters are read.

State Policy

Whatever the national policy may be or become, three great facts are settled so far as Ohio policy is concerned, whether advantage be taken of them or not. These are: (1) Our State is bordered on the north by the greatest water route in the world. That is we have at our northern border, as an outlet for our products, one of the most remarkable instruments of transportation in the world. (2) We are bordered on the south by a water route, which, in its unimproved condition, is the third in the country as to tonnage carried. This river is being improved (as shown on the water map of Ohio in pocket) to a dependable all-year depth of at least 9 feet, *without expense to the State,* and the entire improvement will probably be completed within ten or twelve years. (3) Our commonwealth lies directly in the path of transit of coal from the great Appalachian fields to the West and Northwest, and of ore from the Lake region to the great factories in the Ohio Valley. This general situation is shown on the map accompanying. (Figure 12.) It would seem that Ohio is situated for industrial opportunity, as well as or better than any State in the Union. For example we lead all other States in the production of clay products; this industry ought to greatly expand with adequately cheap transportation.

In preceding pages we have attempted to compare transportation costs on a strictly fair basis. But, whether tolls will ultimately be charged on waterways or not, the National Government is not doing so now on the Great Lakes, and will doubtless not do so for several decades on the improved Ohio River. What this may mean for our State is best illustrated by a concrete example. Let us assume the Great Miami to be improved as far as Dayton, or the Scioto improved for navigation as far as Columbus, or, with the Sandusky, across the State.

Assume the latter for example. The best crude oil for the purpose which is now entering so largely in highway improvement is not produced this side of California. (Our eastern oils are too high priced and have a par-

affin instead of an asphaltic base.) The rate from Bakersfield to central Ohio by rail has been $13.00 per net ton in tank cars of from 6000 to 10,000 gallons. This is a fairly low rate (about 5 mills per ton-mile) when the character of haul is considered (over comparatively heavy grades). Charging a rate of 10 mills per ton-mile for the 170 miles from Bakersfield to Los Angeles, 10 cents for transshipping there, half a mill per ton-mile in tank steamer from Los Angeles via Panama to New Orleans approximately 4200 miles (see transportation map in pocket), $1.50 maximum toll at the Isthmus, 10 cents for transshipping to tank barge at New Orleans, half a mill per ton-mile for barging 1800 miles to Columbus, and 10 cents for transshipping at the last named point, the total charge would be $6.50, or just half the present rail charge.

Of course it may be objected that the charges of water carriers would not necessarily be as low as this figure. But in the long run, charges gravitate to the lowest rates possible with a reasonable return on the investment, and as has just been said, the Government is not now requiring (and probably will not soon require) water carriers to maintain or pay fixed charges on ocean or main river routes. Due to this fact, it has been estimated (see page 26 of 1909 report on Mississippi River) that coal can be carried from Pittsburgh to New Orleans at 0.376 mills per ton-mile, and on ocean vessels of 21 feet draft for 0.35 mills per ton-mile.

Largely due to lack of National Policy, *the policy of our State with regard to waterways,* during the past 20 years or more, *has been in much confusion.* The following well illustrates the situation; pursuant to the recommendation of the chief engineer of State Public Works in 1903, the legislature appropriated $1,500,000 for revamping the Miami and Erie, and the Ohio Canal, *the locks to be rebuilt to the dimensions they had when first constructed, seventy years before**. Of this amount a little more than $500,000 was expended on the Ohio Canal between Cleveland and Dresden, (see water map of Ohio in pocket), at which point it was to connect with improvements to be carried up the Muskingum by the National Government, the Ohio River being still unimproved.

The result at the close of the expenditure was as follows: A canal from Cleveland 100 miles to Port Washington with locks 15 feet wide, 80 feet long, and 5 feet deep on sills, a stretch of dilapidated canal of less capacity 44 miles long from Port Washington to Dresden, a stretch of 90 miles of Muskingum River from Dresden to Marietta with locks 36 feet wide, 160 feet long and 6 feet on sills, connecting with Ohio River having a minimum lowwater depth of 2 feet on the bars on either side of the Muskingum. *If any more striking example of confusion in state and national policies can be cited, the writer does not know it.*

And yet the State Engineer was largely dependent upon Congressional

*See reports of Ohio Board of Public Works, 1903 to 1908.

action. Improvement of the Ohio had been discussed for many years, and it was with the intention of avoiding abandonment of all Ohio canal property for transportation purposes that he recommended the reconstruction mentioned, hoping the improvement of the big river would be decided upon to a depth of perhaps six feet. Congress authorized an examination of the Ohio in 1905, and the Army Engineers in their ensuing report of 1908, recommended a depth of 9 feet, which was definitely adopted by the Government in 1911.

It is not easy to determine when a given mode of transportation is losing its value. It was so with our small canals, and was so with narrow gage railroads, of which we have one still operating in this State. But the Ohio canals were so small, with locks limiting boats to 100 tons or less, that the serious mistake of rebuilding them to dimensions 70 years old should have been avoided. Reconstructing such small waterways was like building a narrow gage track to compete with a modern broad gage railroad. More than a million dollars was thus more than wasted on the Miami and Erie and Ohio Canal together, for, the new locks will have to be removed if any adequate use is ever made of the state canal property for transportation purposes.

The State early resorted to canals as a means of transportation, promptly after the completion of the Erie Canal in 1825. As in the case of the Erie Canal, the Ohio canals justified their construction for early transportation purposes, and greatly benefited the State for twenty or thirty years after they were built. They were then outclassed as an instrument of transportation by the incoming railroads and gradually fell into disuse. As a system they have now been a financial drain on the State for fifty years past. Portions of them can be made paying propositions, but not for transportation purposes.*

Some persons wonder why small canals should not pay in Ohio, when they are used in Holland and in other similar regions of Europe. From what has already been said, the reasons are not far to seek. It is sufficient to point out the radically different natural conditions. In low countries, canals are needed also for drainage, and in such flat country their construction and maintenance costs are low, which contrast with the present situation of the Ohio Canal from Akron to Cleveland. In such swamp lands as those of Florida and lower Louisiana, natural conditions are much the same as in Holland, and small canals are now in use and more are being built in those States. But even in the flat northwestern part of Ohio, where topographic conditions most nearly resemble the low countries, the climatic

*The history of leading facts concerning Ohio canals are briefly exhibited in tabular form in Appendix E. Their history up to 1904 is reviewed in an excellent volume published in 1905, by the Ohio Archaeological and Historical Society. Their situation at present is indicated on the water map of Ohio in pocket herewith at the rear.

conditions are different, the rainfall being only about half that of Holland or of Louisiana, or of Florida, and not as well distributed thru the year for maintaining canal levels.

Other reasons cited in discussing *canalized rivers versus canals,* show why the day has gone by for small canals in Ohio. To amplify each reason briefly, as is done below, will make the situation clearer as pertaining to this State. Why it has not been clear before seems to be due to our political system; our legislators are not long enough in office to become intelligent on the situation, and the term of office of the Superintendent of Public Works is likewise so short that he has not the time to develop a far reaching solution. So, our legislative debates on canals proceeed more or less merrily with inconclusive results at the close of each session.

1. Canals usually follow river valleys because they are cheaper to construct there and can be fed from the rivers. This places them on fertile bottom lands which are most useful for farming. In early days when farm land was plentiful, such use of it mattered little, but with increasing population, we need more and more land for agriculture, especially fertile bottoms.

2. Canals require to be excavated to depth thruout their entire length. River channels are already largely excavated by nature. This is evident of course, but it needs to be stated that rivers usually furnish greater width of way between locks, so that in enlarging transporting capacity the expense is less than for canals. Part of the depth of riverways may be formed by combined locks and dams (with or without levees) impounding the water, and part may be furnished by dredging bars or bed. Dredging is the cheapest form of excavating, and can usually be employed on rivers better than on canals.

3. In carrying canals across stream flowing transversely to the canal, special works must be constructed which are usually costly and troublesome. If a stream is to pass under a canal, an expensive aqueduct is required which is then subject to damage by floods occurring on the stream crossed. Many aqueducts have failed in this manner in Ohio. An aqueduct is, of course, nothing but a bridge carrying water, and such a bridge is subject to the same contingencies from floods that other bridges are. (See State Highway Commissioners map in pocket at the rear.)

4. If transverse streams flow into a canal, they require special works to care for their floods and provide against silting the canal. This is true also of canalized rivers, but not ordinarily to such an embarassing degree. Also artificial banks are not usually designed to pass floods down between them, while river banks in this region are usually already well-trained for this purpose by nature.

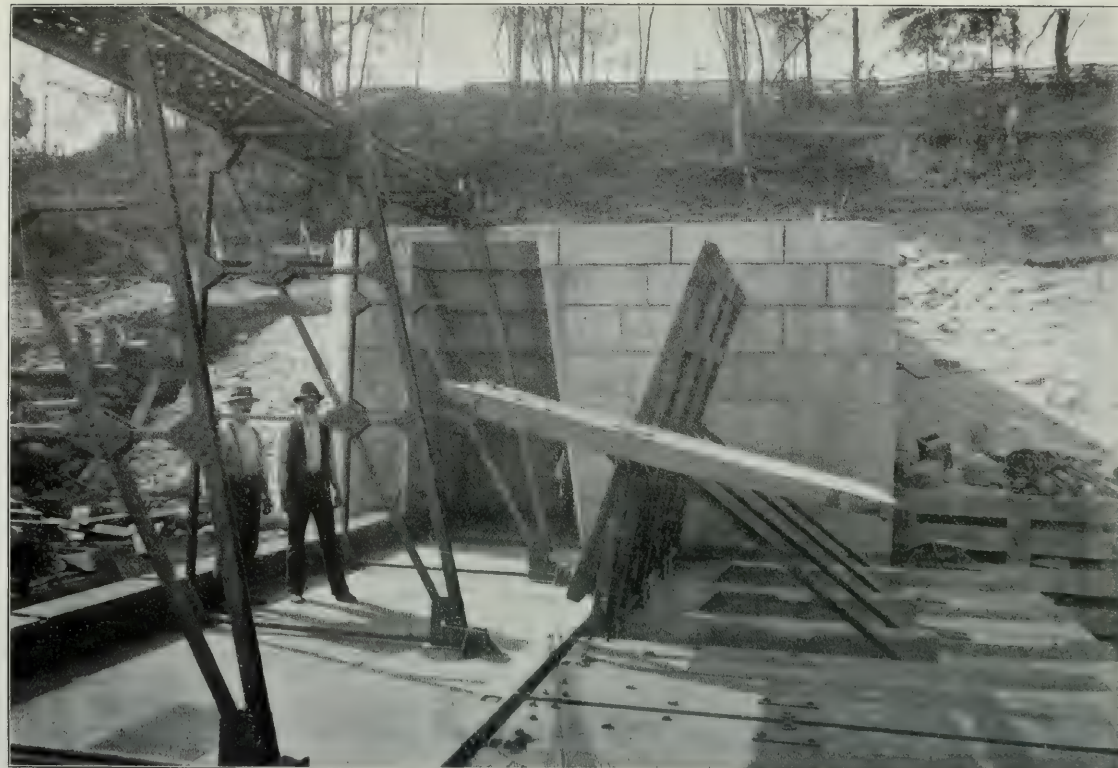
5. Again, canals are often in embankment from which water may seep out onto adjacent farm lands in quantity enough to make them boggy. For this reason canals also require a larger water supply to maintain depth in dry weather. Seepage losses thru one or both banks occur usually along the entire length of canal, while this loss is next to nothing in canalized rivers. The extra water that must thus be supplied to a canal (from either storage reservoirs or feeders from rivers) is very large, as may be seen from page 36 of the Chittenden Report.

6. Canals usually serve the one purpose of transportation, or irrigation, or sanitation, or water power generation, but if they serve any one of these effectively, they usually cannot serve another well, in this region. On the other hand a canalized river may furnish a transportation route and at the same time furnish water power, aid in sanitation by diluting treated wastes, and safely pass a flood downstream.

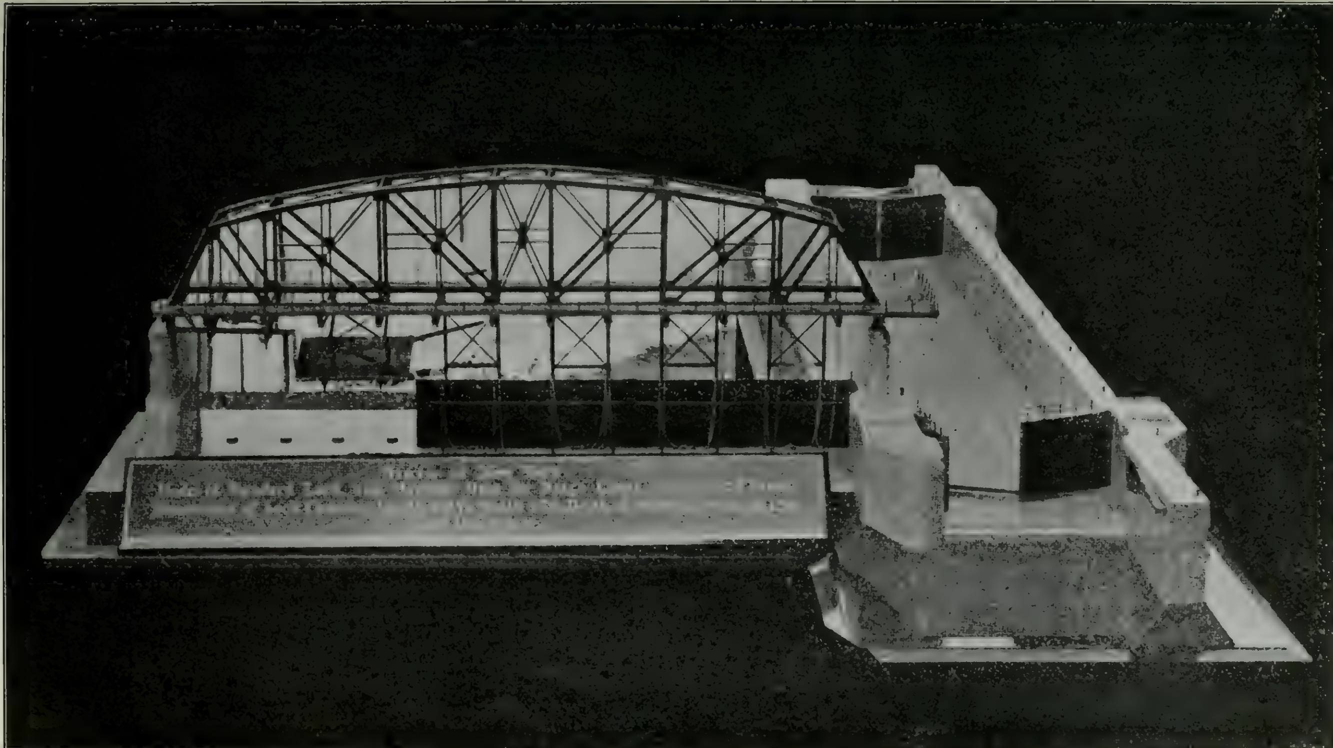
As to floods passing down a canalized river, it might be thought that the necessary locks and dams on such a stream would raise flood hights above normal. In this connexion it should be said that movable dams are in use and are far beyond the experimental stage. There are more than twenty kinds in successful use in various parts of the world, but those employed on rivers fall into two general classes—those allowing floods to pass over them, and those passing floods underneath them. On Ohio River, where highwater is sometimes as great as 70 feet above low-water, they are made to lie flat on the bed of the stream in time of flood. On the Mohawk (where the variation in river stage is not nearly so great as on the Ohio) along the river where canalized for the New York Barge Canal, they are lifted above the water in time of flood. (See accompanying photographs.)

No comprehensive examination of the possibilites of river regulation within our State has ever been made. *The Chittenden Survey of 1895* (the most comprehensive and authoritative examination yet made of our Ohio waterways) *was limited by Congress to transportation only*—and that to vessels of 6 or 6½-foot draft. The Ohio River project was then undecided as between a 6 or 9-foot channel. In fact, it was not even known whether it would be improved thruout at all or not, and the Chittenden Report considered only the unimproved stream. Further, the three routes across the State then reported upon, followed existing or proposed canals except for a few short stretches. The idea of putting the canals into the rivers and treating them simultaneously for other benefits outlined in this paper, in addition to furnishing transportation routes, was not entertained nor permitted by the language of the law making the appropriation for the survey.

In view of the situation outlined in this bulletin, the writer presented



The Chanoine wicket has been used extensively on the navigable passes of Ohio River dams. Both wickets and operating bridge are made to lie flat on the floor, allowing floods to pass over them. Later types are operated from scows without the callapsible bridge.



Eight movable dams of this type have been built on the Mohawk River. Only one span of the operating bridge is shown. In times of flood the dam is raised up parallel to the bridge floor, allowing floods to pass underneath. The extreme left-hand section is raised; the next section (or gate) is partly raised; and the right-hand gates are down in position.

(while presenting the needs of the State Topographic Survey), the proposed joint resolution, given in Appendix F herewith, to the Senate Finance Committee of our state legislature in April, 1913. The great March flood had just occurred, and the general appropriation bills, already prepared and passed by the House Committee, were being virtually redrafted entire by the Senate Committee, owing to flood losses. He hoped, thereby, while national sympathy was fresh, to secure Congressional action, but the time was too limited before adjournment to get an adequate comprehension of the measure before the legislature.

In November, 1913, in the attempt to secure joint state and national action, the matter was presented to the Governor by the executive officers of the State Board of Public Works, State Board of Health, Fish and Game Commission, State Highway Commission, State Geological and Topographic Surveys, in the hope that it might be included in the call for the special session of 1914. It was not so included, largely for the reason that the "Conservancy Act of Ohio" or so-called Vonderheide Act was up for consideration.

The matter was formally presented to the General Assembly in February, 1915, as House Bill 227 by Representative Frank A. Hunter of Franklin County. This bill is given, with one slight amendment suggested by General W. H. Bixby, formerly Chief of Engineers, U. S. A., in Appendix F. Altho favored by the members of the House Committee to which it was referred, yet owing to the drastic policy of retrenchment in expenditures with which the session started, the bill failed to pass. We thus continue penny-wise and pound-foolish in this matter. Ten per cent or less of the million dollars or more wasted on canals from 1904 to 1908, would, if expended for such survey and examination as is proposed, result in saving many times its cost to people of the State.

The special session of 1914, was called to consider the Conservancy Act already noted. This comprehensive law was passed, and the State Supreme Court has within the present year pronounced its main features constitutional. It is without doubt the most sweeping law of its kind to be found in any State in the Union. It grants to perpetual conservancy districts powers of eminent domain, taxing powers, and police powers scarcely inferior to those powers of the State itself. Its scope and purpose closely parallel for the State what the Newlands Bill already noted, proposes for the nation.

Such a sweeping law naturally met with strong opposition. It was feared that such power might lead to great abuse. Whether the law is adequately safeguarded against such abuse remains to be seen, but it may be remarked that great things are not possible without great power, and our American communities are generally so imbued with independence that great abuses are not knowingly endured for long. *The greater danger is*

that petty or unintelligent opposition may too often stand in the way oj accomplishing really great ends.

The law, however, leaves some things still to be desired. It is primarily a law enabling districts to engage in stream regulation, yet it neglects to cover adequately stream regulation for transportation purposes, altho irrigation projects—for which there is little need or opportunity in this State—are especially provided for. It was passed as an emergency law with the one object of flood protection too much in view. It is possible under the law to organize extremely local districts which may execute works militating against subsequent improvement by adjacent territory, and not therefore economically wise from a broader view-point.

For these reasons a wise ultimate plan should be prepared, into which local and district improvements should fit. National interests also are affected by state regulation of those waters discharging into the Ohio. Also the Government owns the principal stream beds of the State.* Therefore, a joint board of competent state and federal representatives should, after state-wide examination and survey, outline the general plans into which conservancy district plans should fit in reasonable degree.

The State owing to its lack of an adequate civil service in the past has no employes who have made life-time studies of stream regulation. This has been the especial field of certain National Government officials, whose assistance should be called in as provided for in House Bill 227 of the last session of the legislature.

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*For example, according to the returns of the original public land survey recorded in the office of the Auditor of State, at Columbus, the Muskingum and Scioto Rivers were indicated as navigable up to the Greenville Treaty line. That is, private property lines along the Muskingum from the mouth up to Stark County and along the Scioto from the mouth up to Prospect above Columbus, extend only to lowwater mark. The United States never sold these streambeds and therefore still retains title to them in fee simple. In addition it has such jurisdiction over their waters as is retained on these river reaches under the definition of navigability already cited in the article on *National Policy.*

CHAPTER VI

WATER POWER

The fact that power can be developed by falling water, be easily converted into electrical energy, and transmitted a hundred miles or more, appeals strongly to those who watch flood waters going by in our streams to waste. Anyone may compute the amount of power possible to generate, by the most simple calculation. To understand the results the two following definitions are given: A horse power is the power of lifting 33,000 pounds up one foot in one minute, or any equivalent rate of doing work, such as lifting 550 pounds one foot in one second. A kilowatt is the same kind of unit as a horse power, but is one-third of a horse power larger. To be exact, a horse power is 746 watts, while a kilowatt is 1000 watts, but it is near enough for our purposes to say that a horse power is three-quarters of a kilowatt. These units are usually abbreviated H. P. and K. W. respectively. If the equivalent of a horse power is put on a switchboard, it is termed an electrical horse power.

A cubic foot of water at the densest (39.3° F), weighs 62.424 pounds or nearly 62.5 pounds. If therefore a stream-flow of 100 cubic feet per second falls 10 feet, the theoretical amount of power that could be generated, would be 100 second-feet, times 62.5 pounds, times 10 feet, which equals 62,500 foot-pounds per second. This amount divided by 550 gives nearly 114 horse power, as the theoretical capacity of the stream at the place of fall.

In this way one might readily compute that the Scioto River between Columbus and Portsmouth is wasting daily an average of more than 40,000 theoretical horse power, because the average river-flow at Columbus (increasing as you go south) is closely 1600 second-feet, and the fall in the 100 miles from the Broad St. bridge to Portsmouth is 219 feet. Such a calculation applied to all the large streams in the State would make it appear that a great amount of power is daily going to waste in Ohio.

But of course it is not possible to realize the *theoretical* amount in practice. Losses in the water-wheels and the dynamos they drive, consume usually 20 per cent or more. If 20 per cent be assumed, the calculation reduces to the following simple rule to find the horse power available: Multiply the second-feet of flow by the fall of the stream in feet and divide by eleven. Or simpler still; the flow in second-feet, (less 10 per cent) represents a stream's horse power for each 10 feet of fall.

Armed with such a yard-stick one might proceed to measure all the water power in the State. Such a crude measurement has already been applied to the whole United States, and the results published in 1909, in the report of the National Conservation Commission. They show that among the States of the Union, Ohio takes a very low rank as a water power State, both in power already developed and in that possible to develop.

It can readily be understood that in mountainous States, the stream-fall is great, and power is correspondingly easier to get. Thus according to the report above mentioned, New York had installed 885,862 horse power, California 466,774 and Maine 343,096, as against 34,840 horse power in Ohio.

Of course, coal is very scarce in the three mountain States mentioned, which is a great stimulus to the use of water power in those commonwealths. Also the market for power is very good in New York, which helps to account for its large development. If California should become as thickly settled as New York or Maine, it will doubtless generate water power far in excess of that of both the latter States combined. Ohio, relatively well supplied with coal, and with comparatively flat stream slopes, has developed much steam and little water power, altho its power market is good.

Another factor comes in where the market is good, which is that this fact of itself usually indicates a more thickly settled region, where lands needed for water storage and development are more expensive to obtain. Railroads and highways and other industrial improvements, which have to be cared for in developing water power projects, often run the cost of the latter, per horse power of installation, to a very high figure. Thus many projects fail from these two opposite causes: development is cheap but the market is uncertain, or the market is good, but development costs too high.

The following instance is fairly illustrative of conditions in Ohio. The writer eight years ago reported on what was then the finest hydro-electric project in the State. It was possible to utilize *the entire annual discharge,* of a stream between Akron and Cleveland, by reservoirs on cheap land, diverting the flow by a short dam only 10 feet high (in a narrow rock gorge) into a canal of 550 second-feet maximum capacity, about five miles long. Altho the drainage basin was small (325 square miles) the fall at the end of the canal was 240 feet vertically in a distance of 1800 feet horizontally, giving 7000 horse power continuously, or 10,000 horse power during a 16-hour day thruout the year.

The market was exceptionally fine, and the development estimated to cost not to exceed $175 per horse power on the last basis above mentioned. Subsequent reports by other engineers reduced the writer's estimate to below $150, altho $250 would have been a justifiable expenditure in view of the remarkable market development which has since taken place. But, before legal entanglements could be cleared out of the way, the region became populated and at the present time is occupied by summer cottages, by one steam-hydro-electric plant using only a portion of the fall, and by an impounding reservoir for a city water supply for Akron. All this has happened in only eight years, resulting in what is, by and large, an uneconomical development for that district as a whole.

The stream above cited happened to be by far the most even-flowing river in the State, which brings us to another obstacle so often lost sight of by those who long to convert flood waters into power. The streams of Ohio, especially in the western half, are among the flashiest in the United States. That is, the difference between high and low-water is extreme. The Scioto at the storage dam, 6 miles above the junction of the Olentangy at Columbus, where the drainage area is a little more than 1000 square miles, has had a range of from 5 second-feet in lowest water to 80,000 second-feet in extreme flood. These flows occurred in August, 1895, and in March, 1913, respectively. Extreme as these figures are, namely .005 second-feet per square mile of drainage-area for low-water and 80 second-feet per square mile for high-water, they are exceeded in both directions on most of the smaller streams of the State, thus making regulation proportionally more expensive the smaller the stream to be treated.

Power must be delivered continuously when needed, or it cannot be sold to advantage. So, when the weather is dry expensively large reservoirs must be used, or a steam plant installed to make good the water power shortage. In either event the unit cost of the total installation usually runs so high, that it becomes a question of whether resort should not be had to a modern steam plant using the cheap coal available in Ohio all the year around. At the Columbus municipal light plant for example, Hocking Valley nut pea and slack has been delivered to the elevating bins as low as $1.10 per ton.

Also as compared with a steam power plant steadily using coal for fuel, a water power project in this region must provide against contingencies brought on by ice conditions in winter. The extensive hydro-electric developments which have taken place during the past decade in our southern States do not have to meet ice conditions.

Again, the advantage of being able to adapt its installation and output more closely to the demand, lies with the steam plant as compared with a water power plant. Flood waters may rush by at a time when there is slight demand for power, and on streams where there is little opportunity for storage. The largest central steam power stations in our great cities keep extra machinery (stand-by units) to serve spasmodic demands. They can sell electric power surprisingly cheap, when this power is used steadily and in large quantity, conditions which the layman usually assumes to pertain to all hydro-electric power. Thus in Akron, power is sold to large factories at a rate of less than one cent per Kilowatt-hour, and in Chicago the Commonwealth Edison Company could doubtless furnish a large quantity, say 10,000 K. W., if taken by the consumer day and night, at nearly half-cent a K. W. hour. This is for power (generated from bituminous coal) delivered in large quantity at uniform load.

The day has gone by for small hydro-electric power plants in Ohio,

except in unusually favorable circumstances, on account of the expense of caring for extreme dry flow, for excessive floods, and for ice conditions, each of which may happen at various times within a few years. The writer knows of no place in the State where a small water power installation, say 100 horse power or less, is advisable. This, in spite of the fact that magazine articles often urge the development of small powers for local use, and that such powers for farms are even recommended in one of the reports of the New York Water Supply Commission.* In Ohio, resort is better had to gas, gasoline, or steam, depending on the size and other circumstances of such proposed small installation.

Finally, we cannot tell what improvements will take place in the next 50 years in steam power generation. It is true that water power machinery is also undergoing improvement, and that at the present time in some instances plant efficiency is almost up to 80%, with water turbines as high as 95 per cent efficient. That is, at present nearly 80% of the power in falling water may be put on the switchboard. But it must also be remembered that at present less than 20 per cent of the energy stored in coal is delivered to the generators, less still going to the switchboard, so that by far the greater possibilities for improvement still lie with steam power generation,

It is often stated that the rapid depletion of coal will necessitate the development of all available water power. Recent reviews of the coal situation thruout the world, thruout this country, and within our State,† altho emphasizing the necessity of careful mining methods and of careful use of mined coal, put the date of serious depletion so far in the future that the considerations listed in the foregoing paragraph, together with other possible improvements in uses of coal and in its mining, come in to give the argument of depletion little or no weight at present.

All the foregoing considerations, and others not here listed, should warn water power enthusiasts to proceed cautiously with development projects. There have been many failures in recently projected water power schemes in various parts of the country. Nevertheless there still may be places in Ohio where such projects will pay, especially when benefits additional to that of furnishing power may be had at the same time. It therefore becomes necessary to determine a safe value to assign to such water power as is capable of being reliably delivered, that is, not counting the power of floods or the extra power available at unusually high stages of water, which latter is commonly called secondary power.

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*Annual report for year ending December 31, 1910, Chapter on Water Power for the Farm and Country Home, by D. R. Cooper.

†For the latter see The Ohio Coal Supply and its Exhaustion (Bulletin 12, College of Engineering, Ohio State University), by F. A. Ray.

Value of Water for Power. For this purpose we make a comparison with steam power generation costs. We use the report for the year ending March 16, 1914, of the Municipal Light and Power Station of the City of Holland, Mich., from which some leading facts are extracted in Appendix D. This example is chosen for the following reasons: (1) The report is a public document available to anyone. (2) It is one of the few municipal plants which makes a complete report. (3) It is operated efficiently high as compared with other similar plants. (4) It is of moderate size and hence more valuable for our present purposes.

The Holland plant, rated at 1800 K. W. capacity (2400 electric H. P.) has been in operation for ten years and its accounts during the latter half of that time at least have been especially well-kept, including apparently all elements of cost, which is rare for a city plant to do. Its installation cost per K. W. of rating is closely $70 up to the switchboard, which is the point where transmission and distribution begins, and which is what we want to compare with water power generation. This corresponds to a value of somewhat more than $50 per horse power at the switchboard.

During the year ending March 16, 1914, the plant burned bituminous coal of about 12,000 B. T. U. costing $2.90 per ton at the plant. Such coal costs about one-third less as an average over Ohio. The Holland plant put on the switchboard for sale during the year, 15.25 per cent of the possible amount it could have generated. This is a fairly high percentage for plants rendering such general service.

The cost of the coal burned was very closely $18,000, or $10 per K. W. of installation. This coal would have cost on an average only about $12,000 in Ohio. Boiler room wages and other expenses incident to the use of coal alone (i. e. the expenses which would not exist were water power used) would however be the same in Ohio as in Michigan. These expenses and cost of fuel amount to about $16,000, or to about $6.60 per horse power of installation. This saving in operation of a hydro-electric over a steam-electric plant capitalized at 6% equals $110 per horse power as the value of water steadily available for generating power. Stated in another way, we may say that on an average in Ohio if a steam plant costs for installation a total of $50 per horse power up to the switchboard, the total justifiable expenditure for a water power plant, including costs of reservoirs, dams, penstocks etc., up to the switchboard, would be $160 per horse power.

We have considered a steam plant within an industrial center, in the foregoing discussion. This does not usually occur in the case of a water power plant, so that the power will usually have to be transmitted. On this account we will reduce our estimate from $110 to $100 per horse power, which is the value we assume stored or otherwise available water will be worth for generating primary power in Ohio. This ought to yield

a net revenue of at least $6 per annum. These figures are meant for general purposes. Individual cases, as already instanced, will vary widely.

The value of water power has been the subject of much discussion in recent years in public documents in connexion with river and other improvements. In the report of the Board of Army Engineers on a 14-foot channel from Chicago to New Orleans (H. D. 50, 61st Congress, 1st Session, "Survey of Mississippi River") the statement is made at page 28, that water powers are reported to have been leased by the Federal Government at rates as low as $ .53 to $2.65 per horse power year on the Muskingum River, these low rates being the best that offered. However, an examination of the form of lease used on Muskingum River shows that these figures are virtually for secondary (uncertain) power.

The other extreme is represented in a statement by M. O. Leighton on page 490, of the report of the Inland Waterways Commission, where after discussing proposed regulation of Ohio River, by storage reservoirs, he assumes the primary power thus developed at Louisville would be worth $20 per horse power year. While it is not definitely so stated, Mr. Leighton evidently assumes the figure just given to be the net revenue per horse power year, for, he capitalizes it at 3 per cent in his subsequent discussion in which he calculates that the total interest charges on the proposed reservoirs, needed to control Ohio River floods, would be paid by revenue from power alone at the Louisville site. This is undoubtedly too high an estimate of the value of water in this instance.

Conclusion. The foregoing two extreme values set on water power by United States Government officials, altho widely at variance, have no wider range than conditions in various parts of the United States might warrant. The figure we adopt, lies between the two and is conservatively low. While water power plant efficiency will not average 80 per cent up to the switchboard, we will assume this figure to be correct because of improvements being made in water power installation, because our estimate of $6 net revenue per horse power is conservatively low, and because the figure is convenient. Therefore, if water is stored for power in connexion with flood prevention or other plans, as illustrated in the Genesee River project already cited, we will assume the stored water to be worth $100 per horse power it can continuously generate thruout a year.

The amount of power stored in a water reservoir is usually greatly overestimated by the average person, as the following example will illustrate. The Columbus Storage Dam impounds 1,720,000,000 gallons, or a three months supply of water for 200,000 people (about the present population) allowing 100 gallons per capita to be used daily, which is a usual allowance. This water turned into power at the site of the dam, would not generate more than 100 H. P. during the three months, nor more than 25 H. P.

thruout a year. That is, a reservoir-full of water would not be worth more than $2,500 for power at the site of the dam. For drinking and other city purposes, the raw water is worth $17,200 per reservoir-full. (See article thereon at a later page.)

However it must be remembered that water stored for power, can be used over and over for the purpose as it proceeds downstream. The power value of stored water varies with the fall. At the storage dam the maximum hight of fall is about 33 feet, diminishing to zero when the reservoir empties. The reservoir-full would all fall thru a drop of 219 feet in flowing to Portsmouth, so that if utilized thruout this hight it could generate 145 H. P. continually thru a year and be worth $14,500 at the $100 valuation we have computed.

However, not all of the fall of a stream can be utilized. Leighton used 90 per cent in making the estimate, already referred to, of power available thruout the country. This is undoubtedly too high a percentage as pertaining to Ohio conditions. In settled communities, property needed for accessories to a power project will usually prevent a considerable portion of a stream's fall from being economically developable. A safer figure would be to assume that half of the stream-fall can in general be developed. It is better, of course, to consider each stream by itself, and not generalize. It may be stated, however, that the more nearly a stream is regularized for all purposes, as is contended for in this paper, the higher will be the percentage of its fall economically developable for power.

What has preceded takes no account of the amount of run-off available for power. On the Scioto at Columbus the average flow under Broad Street Bridge is about 1600 second-feet. At Portsmouth, the average flow for the year approximates four times this amount. But this does not mean, on such a flashy stream, that a large per cent of the average flow could be utilized. If it be assumed that the minimum upper flow could be maintained at 500 second-feet, and the minimum flow at Portsmouth at 2000, then the power available from the average of these, thru one-half the fall (say 100 feet), would be 12,500 H. P. This amount is much more nearly the measure of the value of the river for power, rather than the 40,000 H. P. given in a previous paragraph. The former figure would justify an expenditure of $1,250,000 toward stream regulation for power benefit alone, on the river from Columbus to Portsmouth.

CHAPTER VII

MISCELLANEOUS USES

Other uses of surface water resulting from effective stream regulation are those (1) for industrial purposes, (2) for water supplies for cities and other communities, (3) for sanitary benefits, (4) for agricultural purposes, (5) for agriculture, and (6) for pleasure purposes. We will consider each of these only briefly.

Industrial Purposes

By this term we mean the use of water for steam production, and for manufacturing processes. For steam production water is needed in boilers and for cooling in the condensers of modern steam plants to *an extent little realized by the average person.* At Youngstown for example the large steel mills required so much water for cooling and condensing that a large reservoir had to be built on the upper Mahoning River to maintain better flow in the summer. The summer supply was formerly so small that the factories in using it repeatedly for cooling, heated the water until it was scarcely fit for their own or for city purposes.

Some manufacturing processes require large water supplies. Examples are paper mills and rubber factories where large amounts are needed for washing. Many other industries such as creameries, textile and other factories require ample supplies of cheap surface water, which usually is much softer than the more expensive mineralized underground waters of our State.

Industrial use of water in Ohio will undoubtedly in future greatly exceed in value its value for water purposes. Ohio is well situated to become great among her sister States industrially rather than in agriculture, altho there is room for vast improvement in the latter. The State is well sprinkled over with growing manufacturing centers as shown by the circles on the water map of Ohio in pocket, and our general location with regard to raw products and to cheap transportation, when all modes of the latter shall have been effectively developed, will within the next 100 years place us in the forefront of trade in the Mississippi Valley and North America, if not in trade with the world, if we seize our opportunities in time.

A good illustration of the value of water for industrial purposes is the situation at Barberton and Akron. These two cities are practically one, and together constitute the third largest manufacturing district in the State. This development is directly traceable to an ample supply of good manufacturing water which was developed originally for operating the summit

level of the old Ohio Canal. This water is now nearly all consumed by the great factories, located along the nine-mile stretch of summit level, so that the City has run short and is just now installing a new supply elsewhere, leaving the canal water almost entirely to factories. If the district continues to grow even moderately as compared with the past, within the next fifty years all summit level water will be needed there for main industrial and minor municipal purposes, making the supply insufficient ever again to carry navigation across this summit. There is little doubt that all the water of this summit level system of canal and lakes should be devoted to the uses of factory and town in the future. Included in such uses is the furnishing of pleasure grounds for boating and summer homes.

This same locality also affords a very striking example of the value of water for industrial purposes as contrasted with using the supply for hydro-electric power. The Legislative Committee authorized on April 18, 1913, to report upon the disposition of Ohio canals, in its report the following January cited the desirability of generating electric power from the summit level of the canal. An ensuing examination by the writer developed the following conditions: The canal has an available fall of 130 feet in a distance of 4500 feet, north from the center of Akron. With this fall 1000 gallons of water at 80 per cent plant efficiency (a high figure) could generate one-third of a kilowatt during an hour. If this were sold to net one cent a kilowatt hour (also a high figure) above all operating costs, each 1000 gallons would be worth for water power one-third cent.

An extended examination showed that the net value of the water for boiler use in the factories along the level is at least twice the net value given above for conversion into water power. While it may be urged that this locality is highly developed industrially, and that the water there has therefore an unusually high value for factory use, it is also true that at few or no points elsewhere in the State is there a fall of 130 feet (or even half such a fall) so readily available. Since the power generated by water is directly proportional to the hight of fall, the value of water for hydro-electric purposes is correspondingly diminished elsewhere in the State. It is safe to say that in general over Ohio, water will eventually be worth for factory use, two or three times its value for water power purposes.

Public Water Supplies

It is difficult to realize that in another 100 years or less (say by the the time we have another flood such as that of 1913) the State will probably be more than twice as thickly populated as it is now, and that the search for public water supplies will be correspondingly intense. Yet nothing is more certain than that we will gradually approach conditions that now prevail in older countries in this respect. A trip

around England, France, Germany or older countries will reveal the situation toward which newer countries inevitably tend.

But it is not necessary to go abroad for examples. In New England and other eastern states our future water problems are foreshadowed in the costly water supplies that have been recently installed. New York brings its water in from distances and thru works of magnitude that surpass in both respects the famed splendors of the water works of ancient Rome. In the west, San Francisco and Los Angeles are reaching out for water for 100 miles or more. The conditions of our inland cities one hundred years hence would make a thrilling story could it be read now.

Excepting sunshine and air, no other one commodity is worth more to a community than an abundant supply of potable water, yet there is possibly more disposition to complain against charges for such supply than for any other service. This doubtless arises from the fact that we have not long passed the date when Indians roamed the country and when land, wood, game and water were as free as the air. Each of the first three of these commodities, one after the other, have come to be more and more husbanded, as the population has become denser, and it will be water's turn next.

In Ohio, one brief century has witnessed the passing of the pioneer's cabin from sequestered valleys where water from the streams might be drunk freely without thought of contamination. It has seen on those streams the rise of towns which, emptying their refuse into the rivers, have compelled neighboring communities to seek safe water underground in the gravels of the valleys. It has seen many of the latter towns outgrow the gravel waters, and return to the streams themselves for supply. It has seen the consequent art of water purification highly developed through the necessity of this return to surface water. And a few years more will see the abandonment of practically all underground supplies except in the case of private parties and the small communities of the State.

Even now in our larger cities, away from such bountiful sources as Lake Erie and the Ohio River, the situation has become more or less acute. Youngstown is hard pressed for an adequate supply. Akron has just impounded water which must be brought 12 miles or more to town. Columbus has long outgrown its underground supplies and ten years ago impounded a supply which is fast becoming inadequate to meet its growing needs. Such growing industrial centers as Lima, Marion and Mansfield must soon resort increasingly to surface water, as must also Canton, Springfield, Dayton, Toledo and other places.

The inland city that can furnish good water in plenty at the taps of its users for 10 cents a thousand gallons may count itself lucky. The rates now prevailing at various Ohio cities may be seen in the table ap-

pended as Appendix G, taken from a paper written May, 1912, by F. C. Dunlap, Chief Engineer of the Bureau of Water, Philadelphia.

However, it is the value of raw untreated water that we want. We wish to know the value of a dependable supply of such water in driest weather for municipal purposes. Since in fifty years more, all but the smaller towns will be depending on surface supplies, we select the following two examples as affording a measure of the value of such supplies for Ohio inland cities.

Akron has just impounded a supply on the big Cuyahoga at a cost exceeding $1,000,000 for works and property pertaining to impounding the supply alone, exclusive of purification, pumping and distributing works. The final cost is not yet known, but taking 4½% on the minimum figure of $1,000,000 and adding an annual cost of at least $5,000 for operation, maintenance and depreciation of the collecting works and property, there results an annual charge of $50,000. The total consumption of water by the City in 1913, was about 3,300,000,000 gallons. The supply of raw water thus is costing about 1½¢ per thousand gallons.

At Columbus the uncompleted storage dam on the Scioto 6.5 miles by river above the mouth of the Olentangy, cost $347,990. The lands and other accessories to the reservoir cost $292,210, making a total of $640,200. The amount of water thus made available for a dry season is about 1,600,000,000 gallons. This furnishes a dependable supply of 20,000,000 gallons daily for 80 days for a population of 200,000, which was closely that of the City at the close of 1914. The dependable daily supply therefore totals about 7,300,000,000 gallons for a year. The annual report of the Columbus Division of Water for 1913, shows the consumption to have been 6,276,675,000 gallons, and the operating cost for supply alone (omitting cost of purifying and distributing) to have been closely $4,500. At 4.5 per cent on the investment, plus operating cost, the cost of raw water supply alone was therefore closely one-half cent per 1000 gallons.

The average of the two examples cited shows that one cent per 1000 gallons is a fair valuation for raw water at inland cities of the State. Usually the smaller the community, the more the cost will be. We have taken fair sized cities, Akron at 100,000 population and Columbus at 200,000, in making the above estimate. It may be said that at neither place is the supply adjacent to the town, the cost units given being that for raw water at the reservoir sites. At Akron the water has to be brought from the reservoir through pipes ten or twelve miles to the city. At Columbus the raw water is allowed to flow down the river six miles to the purifying and pumping plant, but additional expense will doubtless be incurred to bring it down in pipes in the not distant future.

Conclusion as to value of raw water for municipal purposes. It is safe to say that in future raw water will be worth on the average at least

one cent per 1000 gallons for municipal purposes to the inland cities of our State. Lands needed for impounding purposes are increasing in value. New uses for water, making it more and more in demand, will develop in future. Looking at the increase in value of water during the past 50 or 100 years, the value above assumed will appear very reasonable during the next 50 or 100 years.

Sanitary Benefits

The sanitary benefits of regularizing a stream ensue from improving the *quality,* aside from the benefit of securing dependable *quantity* considered in the previous article. The cash sanitary benefits are at least fourfold. (1) Regulated flow decreases the amount of suspended material in highwater stages. (2) Decreases the amount of dissolved minerals in low-water stages. (3) Decreases the danger of bacteriological infection for purified and unpurified water supplies, chiefly however for unpurified supplies. (4) Reduces cost of sewage disposal by furnishing more dilution at lowwater stages of streams.

The water purification and sewage disposal plants at Columbus well illustrate the above. Both plants were completed within the past ten years and represented at the time of completion on a large scale the most modern improvements in both arts. From an examination of the annual reports of the Division of Water and Division of Sewage Disposal, it may be seen that a cash saving in operating both plants would result from the improved quality aside from the more regular quantity of water made available were our rivers partly regulated.

The reports do not furnish enough data to calculate the possible saving exactly, but the following is cited to show that the benefits are tangible. The report of the Division of Sewage Disposal for the year 1914, shows that the dry weather flow in the Scioto at the disposal plant (six miles downstream from the mouth of the Olentangy) was between forty and fifty second-feet from June to November, with a minimum of only eight second-feet for nearly half of this time. Such a small flow requires practically complete stabilization of the sewage in the plant before it can be emptied into the almost dry river.

The drainage area of the Scioto at the site of the plant is about 1600 square miles and the average flow thruout the year approximately 1600 second-feet there. Were the stream regulated to a minimum flow of say 500 second-feet, a considerable saving in operating the plant would result by adopting coarse and fine screening, sedimentation and tank treatment similar to that recently used by Dr. Karl Imhof in the Emscher district of Germany. There the even-flowing Rhine has sufficient diluting power to render unnecessary complete treatment of the sewage before discharging

into the river. The irregular stages of the Scioto are responsible not only for increased operating expense but also partly for new additions now being made to the plant.

But a more serious, if less tangible, phase of sanitation should receive our attention. The growth of manufacturing and urban populations has increasingly polluted our waters, and forced the rapid progress now being made in sewage and waste treatments. The situation will, beyond doubt, become increasingly acute in the next fifty years, for there is a growing sentiment that users of water from our streams should return such in as good condition as it was taken. There would be no objection to returning river water in better condition than it was taken from the stream, but this ethical stand may not be reached within the next hundred years, perhaps not within a geological epoch.

Some will object that *conservation is the greatest good to the greatest number for the longest time,* and that upon this basis a large community, to save expense to more people, may pollute a river to the detriment of a smaller town downstream. Thus Chicago upon this theory might pass its diluted sewage thru the Drainage Canal and Illinois River on down to St. Louis. But no such claim was set up in the law suit of Missouri against Illinois and Chicago, when the Drainage Canal was opened, and the United States Supreme Court decided the suit on other grounds. Probably no court now in this part of the country would permit stream pollution on the basis of the above argument, and many rendered decisions are directly counter to it.

Conservation is wise administration, and time alone tells what is wise. This generation suffers now from mistakes of our fathers, by reason of carelessly acquired animal and vegetable pests, for example, (such as the San Jose scale, gypsy moth and others too numerous to mention) and wisdom dictates that we should not pass on to our immediate descendants conditions that may bring them trouble, as sewage apparently disposed of by dilution may possibly do. Many pests now afflicting animals and vegetation were considered innocuous when they were first introduced. City wastes, not completely disposed of, can do no good to succeeding generations, as has been evident at some large cities even when the sewage is thrown into ocean harbors, and it is the duty of the present generation to effectually dispose of its own refuse.

Many towns now pour their sewage into streams or lakes, trusting to dilution to effectually make disposal. It is true that sufficient dilution is at present regarded as a means of disposal, and that for this reason Ohio River has in the past had much economic value as a sewer. Likewise Lake Erie has had, and still has, value as a cesspool for receiving the sewage and refuse from ships that ply its waters, as well as from the cities on its shores.

But that we may be storing up trouble for future generations, even in the case of Lake Erie, is evidenced from the following excerpt from page 41 of the report of the sanitary experts to the Great Lakes International Joint Commission, dated January 15, 1914:

> "In our opinion there is no point from the lower end of Lake Huron to the islands, which separate the western end from the remainder of Lake Erie, from which a safe supply of water could be taken for any considerable portion of the 365 days in a year."

This suggests how rapidly even Lake Erie is becoming polluted, for only a few years ago it was safe to drink water taken aboard boat from almost any portion of the lake except in city harbors. More specific cases are those communities along the lake shore which are now finding their water supplies polluted by their own sewage. Cleveland is now expending a large sum to purify its sewage before discharging it into the lake from which it draws its water. The water near any large lake city is now not safe for culinary purposes on board lake ships.

The examination of Lake Erie has been brought on by the 1909 treaty between Great Britain and the United States, which provides that the boundary waters shall not be polluted on either side to the injury and health of property on the other. This well illustrates on a large scale the universal law that neither a nation, communities or individuals live unto themselves in matters sanitary. It is true, also, that no generation lives unto itself in such matters of health, with respect to its successors.

The situation along the Ohio River is in kind that prevailing along the Great Lakes, only, the political subdivisions involved are not of such magnitude. No state on the Ohio River, has the inherent right to pollute its waters to the detriment of another state, and the United States, (the arbiter between states) through the national health board service, is now investigating the rapidly increasing pollution of the big river. Our own State Board of Health is now requiring those towns on the river, which are building new sewerage systems, to so construct their works that sewage treatment plants may be later installed. If this is true of the Ohio, how much more should the smaller streams of the State receive attention.

The smaller the stream, the drier it gets in summer, as has already been stated. It is during the dry seasons that streams become foul with sewage. Not content with this pollution, we decorate their banks with refuse and rubbish. The pleasure drives in summer all lie upstream from our river cities. Why not reclaim the birthright nature gave us, and make our downstream river drives and boat trips as pleasant as the others?

The Ohio Board of Health should receive the support of every intelligent citizen of the State, in its endeavor to purify the streams. Methods of sewage treatment and of refuse and waste disposal are now well known and effective, and they should be required to be used. There is probably

no more attractive natural feature than a body of clean water. Why destroy any portion of such a feature which appeals so strongly to the instinct inborn in all of us?

Thus it is seen that sanitary benefits of immediate financial value could be secured, from proper stream regulation, in three particulars: (1) We can decrease the cost of purifying and softening water, (2) save some cost in installing sewage disposal plants, and (3) save some money in operating such plants. *But the greater purpose of going farther and completely disposing of all our community wastes now and here,* should be the goal kept in mind not only in order to secure to ourselves but to secure to our successors benefits that are not measured by money, but which none the less exceed in value the three cash benefits named above.

Agricultural Purposes

For agricultural purposes stream regulation may (1) decrease crop losses from floods, (2) promote irrigation, (3) effect drainage of wet lands in some instances, (4) diminish soil erosion, (5) maintain the level of groundwater to greater hight where needed, and (6) furnish frost protection to fruit trees bordering large reservoirs used in regulation projects. Other benefits may be claimed, but they are doubtless insignificant in comparison with those we have just listed.

It is not necessary to exploit each of the above benefits in detail here in the discussion of general principles, because each one has received extended consideration in various publications of the national government, state bulletins, and in many other writings. All such literature that the writer has seen has been too general to be of much practical value. He knows of no specific instance where the values of each of the above benefits have been calculated for a definite project. Hence their worth is largely problematical at this time, and not much of value can now be said in general discussion of such benefits. However they should all be given careful consideration in any specific project.

Records have not been carefully kept of crop losses due to floods on any stream in the country, so far as the writer knows. The worst floods in Ohio usually occur when there are no crops in the fields to be damaged. To the occasional sweeping away of field crops or their destruction by saturation may however be added crop decrease by the erosion of fertile land or by the deposition of gravel thereupon. On this latter score some argue that floods do more good than harm by depositing rich silt on fertile bottom lands, just as the Nile fertilizes its valley in northern Egypt. As far as Ohio is concerned this method of fertilizing land is probably the most expensive one yet advocated.

As to irrigation it is possible that we shall see it applied on a large scale inside the next 100 years within the State. But it should be known

that our annual rainfall, as shown on a previous map (Figure 1), is much greater and more evenly distributed than in those regions of the West where irrigation is now being extensively applied. The flat northwestern part of the State is more favorably situated for extensive irrigation than any other portion, but economical storage of surface water is more difficult in that region than in any other region of Ohio. The question of irrigation may largely hinge on the relative cost of supplementing dry weather on the surface with underground water pumped by windmills when needed, as compared with the cost of storing surface supplies for the occasional irrigation needed. All that can be said on this topic now is that the value of regulating streams for irrigation in Ohio is extremely problematical until some definite project shall have been carefully worked out.

Wet lands or lands frequently overflowed can often be made more valuable by improvements in connection with stream regulation projects. There is little swamp land however in the interior of the State left undrained at the present time. The greatest swamp areas were formerly in the northwestern quarter, but these having been drained are now among the most valuable agricultural lands within our boundaries. Scioto Big Marsh is an example. The largest swamp areas, existing at present, border on Lake Erie, mostly from Sandusky to Maumee Bay, where they would not be affected by stream regulation. The total area of swamp lands at present in Ohio will scarcely exceed 25 square miles, and they lie in scattered patches, so that by stream regulation there is more possibility of benefiting farm lands too often flooded in valleys by streams, than there is of draining swamps by regulation projects. A specific instance will be cited on another page.

Soil erosion may be prevented to some extent by stream regulation, but it would appear that the greater opportunity in this direction lies in methods of cultivation. Contour plowing for one thing is applicable at more places than are now so treated. It is economically impossible to extend regulation up the small streams of southeastern Ohio, where erosion is greatest, and where nature is at her eternal work of leveling the hills. The erosion on the flatter lands is of small consequence, as is attested by the soundings taken on the Columbus storage reservoir after the March, 1913, flood. No measurable silting could then be discovered in this reservoir after it had been in use for eight years.

By maintenance of groundwater-hight is meant keeping the water-table (that is, the top surface of the saturated portion of the soil) so near to the actual surface of the ground that moisture will be available for crops and other uses. After a long continued rain all the ground is saturated and the water-table coincides with the actual surface. But in dry weather the water-table gradually sinks, unless raised artificially by access through the soil to impounded water, or by other means. Water will stand

in the soil at an elevation somewhat greater than that of neighboring pond or stream surfaces, which are the continuation of the underground water-table. Capilarity draws moisture upward in the soil to a certain extent. This benefit might therefore be derived perhaps to a tangible extent in a wide flat valley from regulating its main stream. It would correspond somewhat to subsurface irrigation, which is now practiced in some parts of our country, notably in Florida, where the land is flat and the soil porous.

Around the shores of lakes or large artificial bodies of fresh water, the value of land for fruit growing is increased in tangible measure by the partial protection of crops from damage by frost. The adjacent body of water retards budding in the spring and tempers summer drouth in a way especially beneficial to fruit. Thus Ottawa County has a notable advantage in fruit growing over other counties of Ohio, and an example more widely known is that of the Delaware peach crop, made more certain than that of other states by its favorable position between the Atlantic Ocean and Chesapeake Bay.

It appears then, so far as we in Ohio are concerned, that the effects on agriculture of regulating inland waters have been greatly overestimated, especially in those publications on conservation that are of a general nature. To merely list such advantages as we have done in the opening paragraph of this caption, appears to make a formidable count, but the more such benefits are examined in detail the more they seem to dwindle. Nevertheless, it cannot be doubted that the effects, so far as they go, of stream regulation on agriculture are on the right side of the ledger in each of the counts mentioned.

Aquiculture

Aquatic farming is too new an industry to have gained a foothold in the interior of the State. Outside of Lake Erie our water crops are of little consequence. We have but few lakes within our bounds and none of the streams have as yet been regulated sufficiently to afford opportunity of using them extensively for the purpose.

The subject has been listed here for the double purpose of suggesting that the industry will likely have a future if we engage in stream regulation on a comprehensive scale, and to suggest that the efforts of the State Fish and Game Commission to make our waters pleasurable, and possibly eventually profitable from the standpoint of fish culture, should be seconded by the public. One of the greatest difficulties now encountered by the Commission in keeping our streams well stocked is the killing of fish from combined lowwater conditions and summer stream pollution.

As in the case of many agricultural benefits just discussed, the financial benefits of water crops are problematical, but if intangible they are none the less to be considered. Attention is drawn to an article on the

subject by Professor Herbert Osborn in The Ohio Naturalist, May, 1913. In addition to the production of fish, he lists the growing of shell-fish, aquatic birds, furbearing animals, turtles, frogs, and aquatic reeds for paper, as future possibilities in the way of water farming.

Pleasure Purposes

We have proceeded in this paper from the more tangible, through less tangible to the intangible advantages of stream regulation. No cash value can be assigned to waterways for pleasure purposes, yet who will deny the value of stream improvements for such purposes? A waterway with dependable depth across the State would give great satisfaction to a large number of our citizens. While Figure 12 shows two such waterways now existing across the State, they have legal standing only. Not even a canoe may at the present time cross the State on water.

As previously stated Ohio has practically no natural lakes. The total area of the natural lakes within our boundaries would not exceed ten square miles. (See 1910 report of the Topographic Survey, page 55.) Some of these have been expanded by artificial means. (See water map of Ohio in pocket.) But they cannot now be reached by water. These artificial lakes, even with fluctuating shore lines, are much appreciated for pleasure purposes, as attested by the summer homes rapidly building up around them. The State even derives a considerable revenue from the shores of one small reservoir to which it retained the title. At Buckeye Lake (in Licking and Perry Counties) the State collects annually about $5,000 for shore rent.

This last consideration suggests the advisability of retaining title to the shores of such large reservoirs as may be created in the future. The State has failed to do this at the small reservoirs in Summit County, with the result that the best uses of their shores have not resulted to the public for pleasure purposes. The uses of the waters for pleasure purposes, in the instance cited, is however attested by the boat license fees collected, amounting to $2,441 at Portage Lakes in 1914. The total annual collection by the State for both boat licenses and shore rents at four reservoir sites is at present a little more than $16,000.

CHAPTER VIII

SANDUSKY SCIOTO CONSERVANCY

The foregoing chapters have outlined the general principles upon which it is believed that stream improvement by national, state, or conservancy district interests should proceed. The real nature of stream regulation projects, if they are to be economically sound, shows them to require cooperation between local, state, and national authorities. Conservancy districts, therefore, before proceeding with their projects, should have a wise general plan into which to fit their local improvements. House Bill 227 was designed to secure such wise general plans for the State, and as later developments have shown, is as much of an emergency requirement as is the Vonderheide Law. This will now be shown by specific example.

Preliminary Columbus Project

Promptly after the March, 1913, flood, the City of Columbus took steps to protect itself against such future disasters. Competent engineers were employed to devise plans to protect the city alone. They reported ten projects for accomplishing this purpose, ranging in cost from $23,282,300 down to a minimum of $10,120,600. (See Report of Alvord and Burdick, September, 1913.) One project involving a total expenditure of $11,493,000 was selected as best and submitted to the citizens at the November, 1913, election. It obtained a majority vote, but failed to secure the necessary two-thirds for passage, whereupon an attempt was made to amend our laws so that only a majority vote should be necessary.

This plan, had it been put into effect, would have secured but one benefit, namely, protection from floods, and that for Columbus alone. It would not have increased our city water supply, nor obtained water power, nor a navigable reach available for pleasure or any other purpose already listed. In summer weather it would leave the stream channels thruout most of the city as dry and foul as they are now in low-water. It, however, provides new bridges and drives in place of the old structures spanning the stream at present. These statements are not meant to censure the able engineers who prepare the above-mentioned plans, for it must be remembered that legal authority for preparing a more extensive general plan was wanting, not even the Vonderheide Act being then a law. But we wish to show now, how just a portion of a proper ultimate plan will extend flood protection to a far greater area and secure to the communities in that area, additional benefits which will undoubtedly in the long run exceed the one benefit of the flood protection secured, and all this at an expense not greatly exceeding the minimum estimated cost of protecting Columbus alone from floods.

Of the seven general methods of providing against flood damage listed in the chapter on flood protection plans, but three were employed by the engineers in preparing the preliminary Columbus project, namely, enlarging channel capacity, levees, and detaining dams. The general plan advocated on the following pages and illustrated in the map of divide between Scioto and Sandusky Rivers in pocket herewith (Map No. 2) which we call for short the Summit Level Project, employs two additional methods, namely, diversion of a portion of the drainage area, and storage reservoirs.

Summit Level Project

That is, it is proposed to use: (1) An impeding dam with detention basin above Delaware; (2) regulated storage reservoirs on the upper Scioto and Sandusky; (3) levees on the lower Scioto; (4) channel improvements at Columbus and Delaware, and (5) diversion of a portion of the Scioto drainage basin above Columbus into Lake Erie. The ultimate project contemplates the complete treatment of the entire Scioto and Sandusky Rivers for flood protection, for water power, for navigation, for ample water supply, and for other miscellaneous benefits which we have already discussed.

Of this ultimate project, however, it is only necessary now for us to consider the portion immediately affecting Columbus. It is estimated on following pages (Appendix H), that for a cost of $17,500,000, proper flood protection can be secured, not only for Columbus, but for Delaware, for the entire Olentangy Valley between Columbus and Delaware, for the Scioto Valley from Columbus to Marion, and for the Sandusky Valley from Marion north to the junction of Tymochtee Creek.

In addition, this same expenditure is estimated to secure benefits as follows: (1) An ample raw water supply for Marion, Columbus and all other cities in both valleys for a hundred years in future; (2) a 35-mile reach of navigable water available for barges of 9-foot draft if a waterway is eventually carried across the State; (3) storage of water available for power in future developments on both the Sandusky and Scioto Rivers, but principally on the Sandusky; (4) drainage of the large area flooded almost annually west of Marion as shown on Map No. 2 in pocket; (5) mitigation of floods on the Scioto below Columbus; (6) and many minor benefits listed on preceding pages under Miscellaneous Uses of Water, resulting from proper stream improvement.

The expenditure proposed, amounting in all to $17,500,000 would be extended over a wide territory participating in the benefits, including five counties and many railroads within the affected area, and would involve Columbus for a proportionate expenditure which would not exceed at the most, the minimum estimated cost for protecting the city alone from floods. It would provide a way for the national government also to share a

portion of the expense of perhaps the partial (certainly the ultimate) project, because interstate commerce on water would be benefitted in two ways—(1) flood discharges of the Scioto into the navigable Ohio would be lessened; (2) a navigable reach of 35 miles would be available for the Goverment to connect to, should the ultimate project be later completed.

The most effective single means of accomplishing these results is by the summit level cut with an accompanying regulated storage reservoir as proposed near the headwaters of the Sandusky River, similar to, but on a smaller scale than the reservoir (Gatun Lake), and summit level cut (Culebra cut), already used at Panama. The proposed Sandusky-Scioto summit level cut and reservoir would have all the relative advantages of those at Panama, and even one or two in addition.

Diversion of a portion of the Scioto drainage basin into Lake Erie, is made easily possible by preglacial conditions existing on the divide in this State, as illustrated in the accompanying map of Preglacial Drainage and Main Glacial Moraines. (Figure 13.) Before the advent of the great ice sheet, the waters of the Scioto from all points north of Prospect, flowed into Lake Erie. This is evident from the elevations of the present rock floor underneath the soil as indicated on Map No. 2 in pocket, (and as shown in Figure 15 following), as gathered by the writer from well-records on the Divide during the summer of 1912.

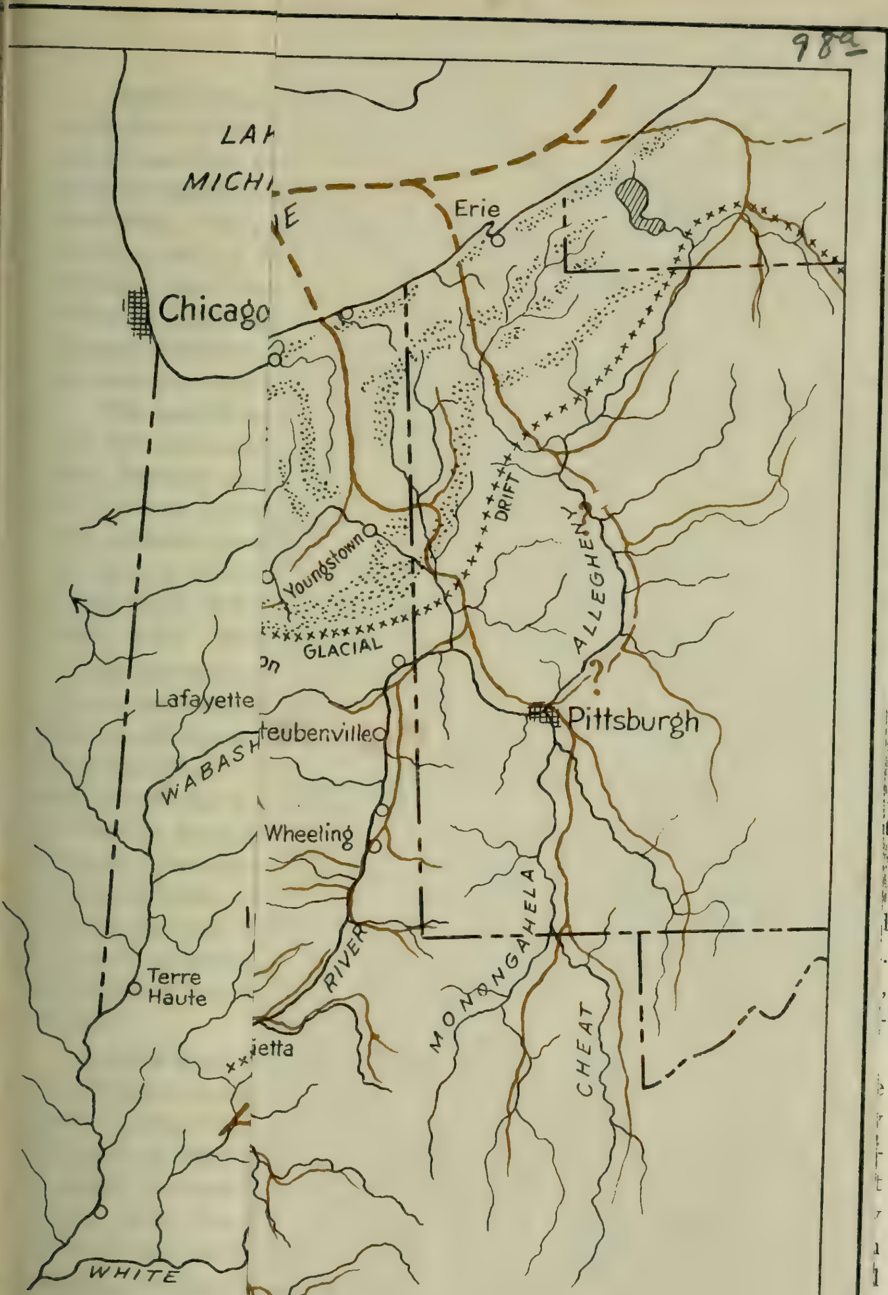
After the glacial ice had come and gone, the preglacial channels were filled with earth and gravel, and a series of moraines were left which turned into Ohio River much water that formerly flowed into Lake Erie. One of these moraines forms the Ohio-Lake Erie divide along the north bank of the Scioto from west of Kenton nearly to Marion, but just west of the latter place the moraine is so low that *in March, 1913, a small portion of the Scioto flood waters escaped over the summit and flowed down into Lake Erie.*

These conditions are well shown on the accompanying map of Preglacial Drainage and Main Glacial Moraines. The Scioto from west of Kenton for a distance of 30 miles east, receives no tributary from the north. This is an unusual river condition, and is due to the fact that a glacial moraine, like a large flat levee, forms the north bank of the river. The effect of glacial moraines on the preglacial drainage of the Maumee and Wabash River systems is also strikingly shown on the map, and it is interesting to note at this place, that *in March, 1913, a portion* of the Maumee flood escaped over the divide and flowed down its ancient course* (the Wabash Valley) *to the Mississippi and the Gulf.*

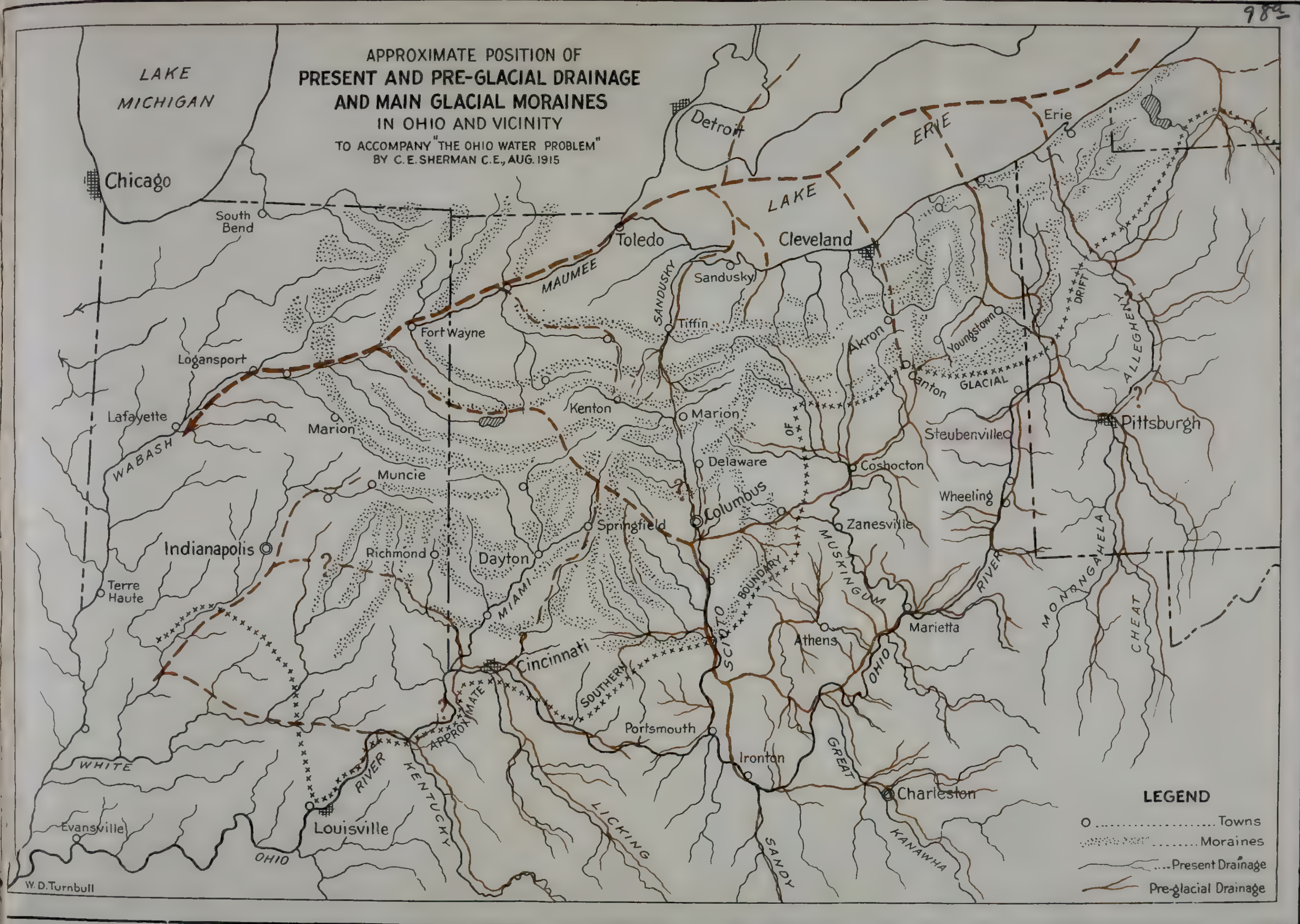
Still another feature, to which attention is now called, is the fact that these moraines north of Marion lie in concentric belts, affording possibilities for great storage reservoirs between them, by damming the gorges cut thru the moraines by the north-flowing Sandusky and Tymochtee.

* Stated to be 10,000 second-feet at crest by Prof. W. K. Hatt of Purdue University.

98a



ample concrete spillways, with sluices and gates similar to the Keokuk


APPROXIMATE POSITION OF
PRESENT AND PRE-GLACIAL DRAINAGE
AND MAIN GLACIAL MORAINES
IN OHIO AND VICINITY
TO ACCOMPANY "THE OHIO WATER PROBLEM"
BY C. E. SHERMAN C.E., AUG. 1915
LAKE MICHIGAN
Chicago
South Bend
Detroit
LAKE ERIE
Erie
Toledo
Cleveland
Sandusky
MAUMEE
SANDUSKY
Tiffin
Fort Wayne
Logansport
Akron
Youngstown
Canton
GLACIAL
DRIFT
ALLEGHENY
Lafayette
Marion
Kenton
Marion
Pittsburgh
Steubenville
WABASH
OF
Muncie
Delaware
Coshocton
Columbus
Wheeling
Springfield
Zanesville
Indianapolis
Richmond
Dayton
MUSKINGUM
MONONGAHELA
Terre Haute
BOUNDARY
RIVER
MIAMI
Marietta
CHEAT
Athens
Cincinnati
SCIOTO
SOUTHERN
OHIO
APPROXIMATE
Portsmouth
Ironton
GREAT
WHITE
RIVER
KENTUCKY
Charleston
Louisville
LICKING
Evansville
OHIO
SANDY
KANAWHA
LEGEND
Towns
Moraines
Present Drainage
Pre-glacial Drainage
W. D. Turnbull

Some of these reservoir possibilities are shown at **A** and **B** on the water map of Ohio in pocket, and from the capacities marked thereon it can be seen that the capacities available for storing water in the Sandusky basin far exceed anything economically possible on the upper Scioto or Olentangy. For example, the hights of proposed dams **A, B** and **C,** storing 23, 9 and 1.5 billion cubic feet respectively, are 70, 65 and 50 feet respectively above stream bed. Map No. 2, in pocket, also shows a portion of these storage possibilities much more clearly, and the whole situation becomes evident from a study of the maps of the Ohio Topographic Survey which are too extensive to reproduce in this bulletin.

The summit level cut, then, as shown on Map 2, would be thru glacial drift, not rock, and would not need to be very deep for diversion purposes alone, because the present elevation of the lowest point in the Scioto River bed at Green Camp (where the river turns south) is 892 feet above sea level, whereas the divide at the highest point where the proposed cut is to pass thru, is 918 feet above sea level. It was near this latter place, thru a small ditch, that a part of the Scioto flood escaped into Lake Erie in March, 1913. (See figure 15 and map 2.)

Our estimate of $17,500,000, however, includes the cost of digging this cut much deeper than that necessary for diversion of floods alone, in order to effectively drain the flat area of valuable land west of Marion flooded in March, 1913, (as shown in Map No. 2), and to keep the two reservoirs **B** and **C** connected at all times, thus virtually making one great reservoir of them both. For this purpose the bottom of the cut has been assumed to be placed at elevation 880 and has been made 210 feet wide at that elevation with side slopes 2 to 1. Also this cut has been extended south in the river bed from Green Camp to 5 miles south of Prospect. Rock will be encountered on this portion of the cut, lying in the river bed, and this part has therefore been figured at $1.00 per cubic yard for excavation.

Coupled with the summit level cut, the estimate includes a 3-mile side cut to Marion as shown on Map No. 2 (or it may be located approximately parallel to itself farther north or south), for the double purpose of diverting floods of the Little Scioto, and for giving Marion access, by water, at all times, to reservoirs **B** and **C**, and the waterway, if such is ultimately carried across the State. That is, the bottom of this side cut has been figured at the same elevation as the main summit cut, and water would normally stand in both at the same depth.

The dams at **B** and **C** would be similar in character, about 65 and 50 feet high respectively above stream bed, but neither would be simply an impeding dam. They would be surmounted by roadways 10 feet higher, from which the gates could be operated. They would be provided with ample concrete spillways, with sluices and gates similar to the Keokuk

dam or the Gatun spillway, so that the water in both reservoirs could be simultaneously maintained to any elevation desired, between 880 and 900 or even 905 feet above sea level. For example, if desired, during February and March, the water level thruout both reservoirs could be kept down to 885, and then allowed to rise after greatest danger of flood has passed.

Thus water could be fed down north or south from the combined reservoirs **B** and **C**, or fed in both directions simultaneously. The dam at **C** is at the same location (White Sulphur) as proposed by Messrs. Alvord and Burdick in one preliminary Columbus project, but as here proposed would not be a detaining dam only. With the summit level cut as proposed, dam **C** would ordinarily enable more than half of the flood waters of the Scioto above Columbus to be turned northward into large reservoir **B** as shown in accompanying cut of Diversion Possibilities (Figure 14). Even if this dam **C** were to be moved farther north to just above Prospect, (near the Marion County line) where it need not exceed 25 feet in maximum hight, it would still ordinarily enable half the flood waters of the Scioto above Columbus to be turned into Lake Erie.

Diverting upper Scioto floods into Lake Erie at once raises the question as to the advisabilily of passing additional calamity north down the Sandusky Valley, instead of south down the Scioto where it now passes. *This question is easily answered.* Scioto floods passed north thru the summit level cut, enter the great summit level reservoir at the north end of the cut. This reservoir would act precisely in the same manner that Gatun reservoir does on the exceedingly violent Chagres, as already explained in connexion with the map of Panama Canal on a previous page. Not only would this reservoir render upper Scioto floods harmless, *it would also protect from sudden freshet* (such as the upper Tymochtee, upper Scioto and upper Ottawa Rivers had on July 16, last) *the valley of the Sandusky River* thruout Wyandot County to the junction of Tymochtee creek.

Further, contrary to general impression, the greatest stream-fall, concentrated at suitable places for water power development, is on the Sandusky River, not on the Scioto. Stored flood waters would thus be of most use on the Sandusky. Thus in the 5-mile reach, from Tiffin north, the Sandusky falls 73 feet, and in the vicinity of Fremont there is a natural river fall of 50 feet in a distance of only 4 miles. Nowhere on the whole Scioto from headwaters to mouth are there similar reaches with such amounts of fall, or even half such fall. This situation is therefore remarkably opportune for future power development on the Sandusky if surplus flood waters are to be stored on this river, and we will recur to the subject at more length later.

Attention is now directed to the greatest storage possibility of all, namely, that at the junction of the Sandusky and the Tymochtee. This

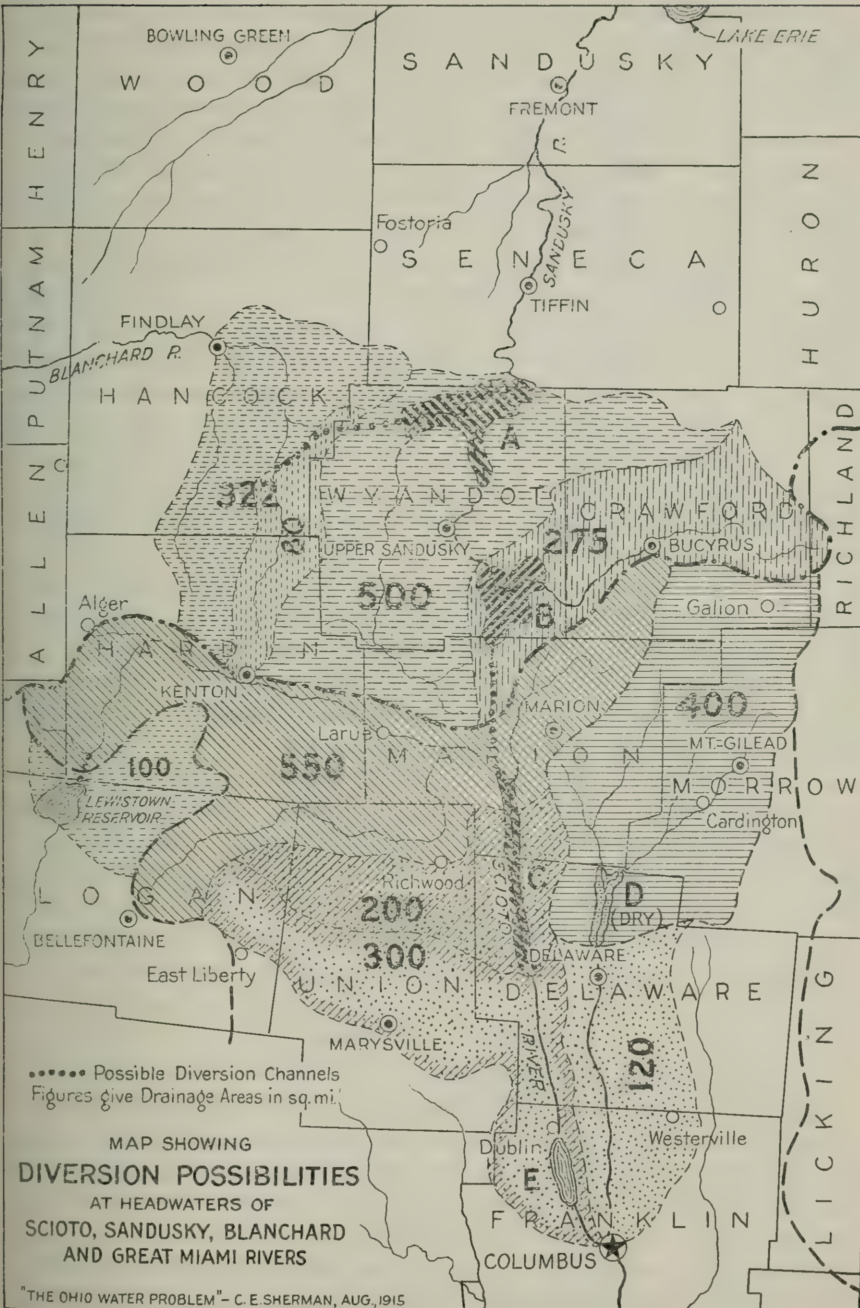

BOWLING GREEN
WOOD
SANDUSKY
FREMONT
LAKE ERIE
HENRY
HURON
Fostoria
SENECA
SANDUSKY R.
TIFFIN
FINDLAY
BLANCHARD R.
HANCOCK
PUTNAM
A
322
30
WYANDOT
CRAWFORD
UPPER SANDUSKY
275
BUCYRUS
RICHLAND
500
Galion
B
Alger
HARDIN
KENTON
ALLEN
MARION
400
MT. GILEAD
Larue
100
550
MORROW
LEWISTOWN RESERVOIR
Cardington
Richwood
C
D
(DRY)
LOGAN
200
300
BELLEFONTAINE
DELAWARE
East Liberty
UNION
MARYSVILLE
120
LICKING
•••••• Possible Diversion Channels
Figures give Drainage Areas in sq. mi.
MAP SHOWING
DIVERSION POSSIBILITIES
AT HEADWATERS OF
SCIOTO, SANDUSKY, BLANCHARD
AND GREAT MIAMI RIVERS
"THE OHIO WATER PROBLEM"– C. E. SHERMAN, AUG., 1915
Dublin
E
Westerville
FRANKLIN
COLUMBUS

Figure 14

site we have designated Reservoir **A.** It is just outside the limits of the large scale map (Map No. 2 in pocket), but has been indicated on the water map of Ohio (Map No. 1 in pocket), and on the accompanying cut (Figure 14), showing Diversion Possibilities. Should it be desired later to control the floods from the Tymochtee also, Reservoir **A** not only can do this completely, but can also regulate the entire remaining river reach from the reservoir to Lake Erie. We will revert to this later under the caption Ultimate Project.

Summit level Reservoir **B** has a capacity of 9,000,000,000 cubic feet or more. This capacity can better be realized when we say that it is equal to the capacity of 36 reservoirs similar to that above the Columbus storage dam. This great capacity is exclusive of the summit level cut and of Reservoir **C** (it can store 1.5 billion), which, as already stated, really constitute with **B**, one great summit level reservoir 35 miles long. (See Map No. 2, or Figure 15, which has been taken from Map No. 2.) The capacity of Reservoir **B** can be indefinitely increased if desired, by extending it westward as shown on Map No. 2, but the great capacity already provided is sufficient as will be shown.

By raising the highway, which bounds Reservoir **B** on the west, to form a levee, and detouring the Hocking Valley Railway west, and carrying it along the west side of this levee, Reservoir **B** is confined to the lands that are cheapest, which give greatest average depth to stored water, and which place the latter in the direct line of traffic, should a waterway eventually be carried across the State in this region.

Our estimate of $17,500,000 has included cost of all these improvements, including road changes, bridge construction, property damage, and $2,300,000 for channel improvements at Columbus, and $150,000 for similar work thru the City of Delaware. The latter figure in connexion with the detaining dam above Delaware, will be ample to care for necessary improvements at that place, judging from a report on flood protection made by the writer in August, 1913, to the flood committee of Delaware.

Operation of the Project

In the article on flood possibilities in Chapter II it was shown that we cannot be absolutely safe against nature's forces. Only partial protection is possible. It is not, therefore, economically wise to provide for a greater storm than that we experienced in March, 1913. As explained in the chapter on floods, local floods of extreme violence are liable to occur at any part of the State against which we are powerless to completely provide. Furthermore, we have shown that in widespread long-continued storms, such as that causing our great March flood, the distribution of rainfall will never be twice alike.

We, therefore, assume an equivalent storm, that is, a rainfall produ-

cing flood volumes or hights equivalent to those of March 25, 1913. Assuming the ground to be already saturated, a rainfall of three inches daily, continued steadily for two days, uniformly over the basins, will produce floods of the dimensions then experienced on the area now under consideration, namely, the whole Scioto and Sandusky basins from Columbus to the junction of the Tymochtee and Sandusky (near the Seneca County line). As a matter of fact this assumed precipitation is somewhat greater than the average rainfall on the total area just mentioned during the high flood-crest-causing portion of March, 1913, storm. But we will assume it nevertheless, and will now consider the effect of our summit level project (shown on Map No. 2) on floods ensuing from such a rainfall. Such a storm we may reasonably expect not oftener than once in fifty years, probably not oftener than once in a hundred years.

Let us assume the worst possible operating conditions at the outset; that is, that the reservoirs are completely filled when such a storm comes on. When the reservoirs are full to the maximum hight they are ever intended to reach, the water surface is at elevation 900 as shown on Figure 15 and Map No. 2. The water in the summit level cut is then 20 feet deep and extends down the Scioto at this depth to below Prospect, where it joins Reservoir **C**, standing at the same level.

The area of Reservoirs **B** and **C** at the 900 contour is 28.5 square miles. The drainage area tributary to them (as best shown in Figure 14) is closely 1,025 square miles, or 36 times the reservoir surface. Therefore, one inch of rain on the whole region running into the reservoirs, would raise them 36 inches, if the surface did not expand above the 900 foot level and if none of the run-off were allowed to escape from the reservoir. But reservoir areas expand with the increasing hight of water. Due to this fact the whole first day's rain (3 inches) over the 1,025 square miles would raise the reservoirs not over seven feet, and the second day's rain not over five feet additional, all this on the assumption that none of the flood waters of the two days were allowed to escape from a reservoir already full when the storm began. That is, with Reservoirs **B** and **C** full, and a six-inch run-off from the whole tributary basin (this amount is half of our average run-off for a whole year), running into them and not allowed to escape, the surface would not rise over 912 feet elevation.

This would be no higher than it rose along the Scioto from Green Camp down during the 1913 flood, while at the same time the water would be robbed of the destructive velocity it had then. It would be lower than the 1913 flood water in the area west of Marion. This reduction in hight would be due to the new outlet north through the summit level cut permitting the water to spread out over the surface of large Reservoir **B**. This latter effect of reservoirs is well set forth by General Chittenden in an interesting discussion of flood control by reservoirs, in his preliminary

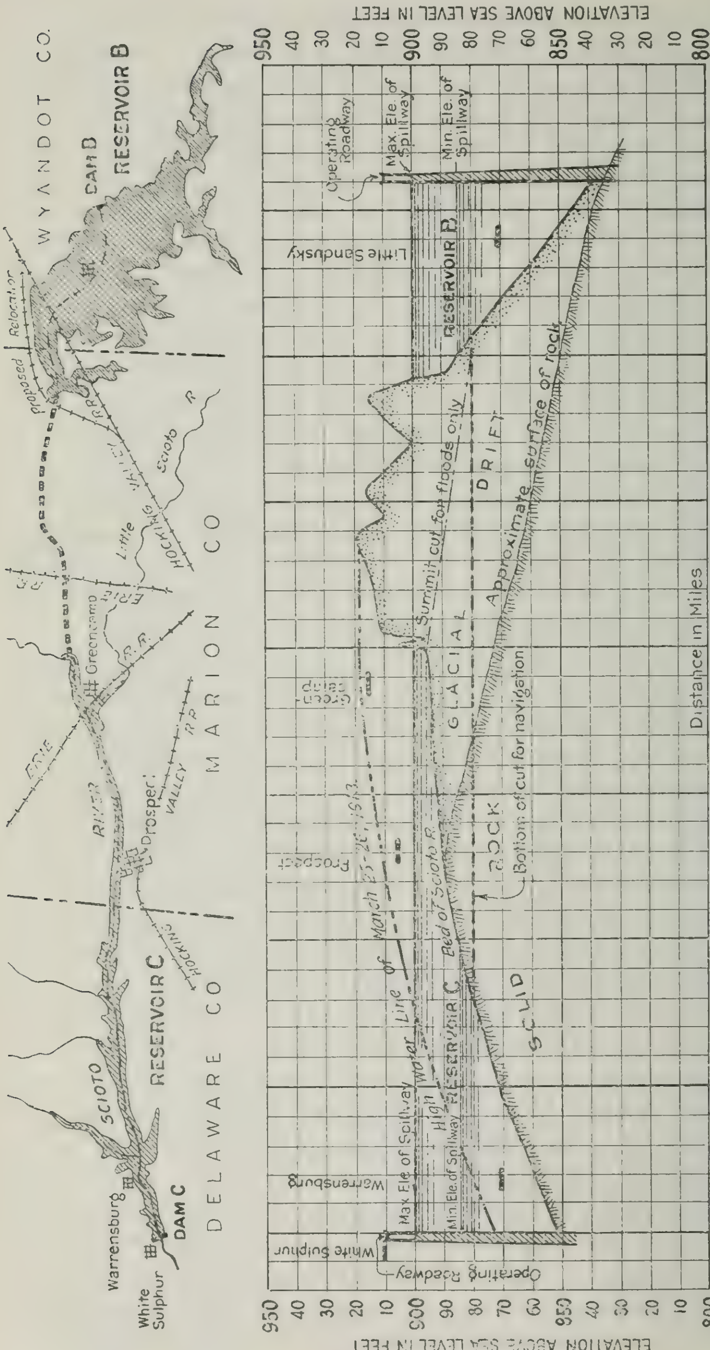


FIG. 15

REPRESENTATIVE PROFILE OF SUMMIT-LEVEL PROJECT

Owing to smallness of horizontal scale the sections of dams can not be correctly represented. They are of the usual gravity section similar to the Columbus storage dam. The sketch above the profile shows relative position of reservoirs and Summit cut. See Map No. 2 in pocket.

report which was virtually the beginning of the great irrigation works in the West. He said:

> "It is not necessary, though important, that a reservoir should be empty when a flood comes, Even if full, it still moderates the flow of the stream below, the effect varying directly with the superficial area of the reservoir when full, and inversely with the capacity of the spillway. In this respect it acts precisely as does a natural lake. For example, if the spillway of a reservoir or the outlet of a natural lake be of such dimensions as to require a considerable increase in the depth of water to give much of an increase of discharge, every increment of this depth of outlet means also an increment of the same depth over the entire reservoir. A flood passing such a reservoir will be reduced by the storage resulting from this increment, and before it can produce a full discharge it must fill the reservoir to the necessary hight above the bottom of the spillway. A large reservoir is, therefore, even when full, always a perfect protection against sudden floods. In the case of long continued floods it greatly retards the arrival of maximun effect and gives ample notice of its approach."

But *(still assuming the above flood came on to reservoirs full)*, a limited portion of the flood water may be passed both north and south at dams **B** and **C** during both the first and second days, instead of keeping the stream channels immediately below both those dams totally dry for two days. Thus if fifteen and twenty thousand second-feet were passed north and south respectively during the two days, (this would be equivalent to lowering the reservoirs about 3.5 feet daily from contour 900) the maximum flood hight within the reservoir area would be kept down to an elevation where little or no danger would ensue in the area between dams **B** and **C**, while at the same time the flood flow down the Sandusky and Scioto would be greatly reduced from what they were in March, 1913. For example, the flow at the Columbus storage dam would be 45,000 second-feet (at crest) under the above worst conditions assumed, instead of 80,000 second-feet as it was in March, 1913.

But the reservoirs may be operated much more effectively still. As already stated on earlier pages, the upper portion or layer of reservoirs **B** and **C** may be kept for flood catchment. Suppose the water surface be kept at 890 during winter months. Then if our three-inch rain lasting two days came on, it would have to fill the empty portion of the reservoirs first while at the same time the regulating gates at both dams could be discharging such small amounts as were desired. One-inch run-off from 1,025 square miles equals 2.4 billion cubic feet. The storage capacity of the upper ten feet of reservoir up to contour 900 is 5.5 billion cubic feet. (See Appendix L.) This capacity with a foot or two additional would nearly take care of the entire first day's rain without letting any escape. With the discharging gates in proper operation, the entire two-day rainfall could be handled without damage, either to the summit level area or the river valleys below.

Finally, the reservoirs can be operated far more effectively still if only flood protection is desired for the whole summit level area and the valleys below, both north along the Sandusky and south along the Scioto. The water surface may be kept down in winter and spring to elevation 885 or 880, or the reservoirs may even be kept dry by properly arranged sluice pipes and gates in both dams. We have assumed in the foregoing paragraphs that their surface elevation was kept up to such hight that ten-foot depth was available for navigation at all times across the summit, and have shown that this can be done and at the same time flood protection be secured. All this and many other advantages can be realized from a study of the accompanying cut (Figure 15) and Appendix L.

The detaining dam above Delaware would operate to reduce the discharge of an excessive flood thru that town to less than one-half of what it would otherwise be. That is, this dam might be of the type proposed for the "dry reservoir" protection of Dayton and the lower Miami Valley. The maximum flood discharge thru Delaware in 1913, was about 45,000 second-feet. With an impeding dam and detention basin reducing the flow to 20,000 second-feet this flood could be readily cared for by the present channel of the Olentangy thru the city, with only minor bank protection and other improvements in the way of cleaning out underbrush and other obstructions in the channel.

To the 20,000 second-feet thus passing Delaware during the widespread flood conditions we have assumed, would be added flood waters falling on the 120 square miles of Olentangy basin between Delaware and Columbus, swelling the volume to about 30,000 second-feet at the mouth of the Olentangy, where it would be joined by 45,000 second-feet maximum Scioto flood passing the present Columbus storage dam. Therefore the channel thru Columbus should take care of the combined flow amounting to 75,000 second-feet, in case of another great flood, and $2,300,000 has been included in our estimate to clean out the channel and replace all bridges with better reinforced concrete arch bridges.

Thus a flow thru Columbus from a storm equivalent to that of March, 1913, if the summit level project were built as here proposed, would be only about one-half of that which passed thru the city in the great flood. That is, the flow would be reduced to 75,000 second-feet instead of the 140,000, which then passed thru the city. This reduction in flood volume would be a great help to the Scioto Valley below Columbus as far as Chillicothe.

Further, the above reduction in flood-volume thru the city would enable the waters to be passed down the present channels with but little enlargement and expense as compared with that necessary to pass the whole 1913 flood, for the reason that the channel for the larger flood-flow would require condemning property thru expensive territory, as the report on the preliminary Columbus project showed. For the reduced flow,

it is estimated herewith that $2,300,000 would cover the expense of the necessary enlargement of present channels, including building additional spans on the railroad bridges, and replacing the present and destroyed bridges with new and longer concrete arch bridges on strong foundations, and replacing necessary levees.

Attention is now called to the effect of the summit level project on sudden and local freshets caused by summer thunder showers, similar to that of July 15 and 16, 1915.* Such a storm occurring on the Sandusky thruout Crawford County would be completely absorbed by Reservoir **B**. Such a storm on the upper Scioto would still flood the extreme upper headwater-lands (known as Scioto Big Marsh), but would be prevented from flooding the area of about 23 square miles which were flooded in March, 1913, as shown on Map 2 in pocket, because the present lowwater surface in the Scioto at Green Camp is 897; whereas, the bottom of the proposed summit level cut is at 880 with water surface normally 10 or 15 feet higher, giving an additional and a much more effective outlet north to such flood waters than they have at present.

Thus under worst possible conditions of operation we find that both the summit level area and the valleys of the Sandusky, Scioto, and Olentangy Rivers would be greatly benefitted by the summit level project; and that if rain gaging and river gaging stations in these valleys were properly provided with communication with each other, and with operators at Dams **B** and **C**, so that the gates could be operated intelligently, complete flood protection from such storms as that of March, 1913, would be provided for the whole area from below Columbus to nearly Tiffin.

Local damage arising from thunder showers like those at Cambridge and Zanesville shown on previous pages, and such as that which occurred July 16, 1915, on the area at extreme headwaters of the Scioto in Auglaize and Hardin Counties (known as Scioto Big Marsh), would not be provided for; nor is it possible to completely provide for such floods by any feasible flood protection project. The summit level project would, however, protect from such local storms the summit level area thruout Delaware and Marion Counties and the valleys of the three streams thruout these counties, including the Sandusky Valley to its juction with Tymochtee.

The work of establishing river gaging stations above mentioned has been too long delayed in this State. Many other states are doing this work (see 35th Annual Report U. S. Geological Survey, page 118) in cooperation with the National Government, and have been collecting valuable data, as we should be doing. Attention is called to the matter here, simply to show how far we are behind other commonwealths in studying our water resources. The writer attempted in April, 1913, (in connexion with the appropriation for the Topographic Survey) to get a small appro-

*See Appendix M.

priation ($2,500) with which to begin cooperation with the national authorities. It would have been an excellent investment, and the work should not be delayed longer.

Estimate and Construction

Appendix H gives estimated cost of the summit level project at $17,500,000. We believe this estimate is high. For example, in Appendix K, so far as conditions are known, the engineers of the Marion Steam Shovel Company estimated that the summit cut can be made for six cents per cubic yard. Ten cents has been used in our estimate. Of course an extensive survey and estimate of the whole project, with borings on the summit should be made. This the writer has not had time to do, and information is at present limited to well-records, topographic maps and a few very limited field examinations made at private expense. But, as in the estimating of cost of the summit level cut, the writer has attempted to get all figures reasonably high. Land for example at the reservoir sites has been figured at $100,000 per square mile, or at about $156 per acre, while the present market price at such places (in Reservoir **B**) as have been ascertained, is from $75.00 to $100.00 per acre. The estimate of Appendix H was made by experienced construction engineers under the writer's direction.

But even at $17,500,000 the results obained are positive. That is, instead of expending $11,500,000 for the one benefit of protecting property within Columbus corporate limits from a flood which may occur only once in a century, we would have flood protection extended over the great area already shown, and above all secure other positive benefits to the whole areas that will doubtless exceed in the long run the value of such flood protection.

The project need not all be constructed at once. Thus if the detaining dam were first built above Delaware, that town and the whole Olentangy Valley south would be rescued from flood, and floods at Columbus would be greatly mitigated. Next, if Reservoir **B** were constructed by building Dam **B** and the three-mile levee along the west side, a shallow summit cut sufficient to relieve both Scioto and Sandusky floods, might be put thru, and this cut dredged deeper as proposed for navigation at a later date.

Therefore, many modes of procedure, not reviewed here, should be considered before construction is begun, and preceding all a comprehensive survey and examination, not only of the summit level project, but also of an ultimate plan for the whole Sandusky and Scioto Valleys should be made with reasonable care, to ascertain its bearing on the summit level project including local channel improvements.

Ultimate Project

The limits of this paper preclude extended discussion of complete treatment of the lower waters of both Sandusky and Scioto. We will, therefore, only briefly suggest, in what follows:

On the Sandusky River just north of the junction of the Tymochtee Creek, a dam seventy feet high in the narrow valley cut through the glacial moraine would impound an immense quantity of water (23,000,000,000 cubic feet), or an amount nearly equivalent to one hundred times that in the Columbus storage reservoir. Should this dam be built it would completely protect from devastating floods the entire river valley below it, including the cities of Tiffin and Fremont—thruout Seneca and Sandusky Counties to Lake Erie.

This artificial lake, (marked **A** on the maps), would also furnish eighteen miles of navigable route of ample depth and store a great quantity of water available for power at the site of the dam, which same water would be more valuable still for power thruout the 73-foot fall near Tiffin, and at the fall already partially developed at Fremont. If the reservoirs were simultaneously used for transportation, the necessary lockage would subtract some water from power production, but only a comparatively small amount, even with heavy traffic. If Reservoir **A** is built, not so much expenditure will be needed down the Scioto as we have calculated for the summit-level project, for the reason that **A** is so large that all flood water from both the Sciotos above Prospect and from the upper Sandusky can be cared for by **A** and **B** together. *This illustrates again why a general plan of treating the whole Sandusky and Scioto Valleys from Lake Erie to Ohio River should be studied before the more local plans are drawn.* It is likely that not nearly so large a reservoir as has been figured would be needed at **A** to accomplish the above purposes.

The level of Lake Erie extends up the Sandusky to Fremont. This reach of river would require some deepening and straightening for nine-foot barge navigation. Other reaches between Fremont and Reservoir **A** would require canalization, but not more than fifteen locks would be required on this portion in addition to locks at Dams **A** and **B.** Sandusky Bay is sheltered to some extent from storms sweeping the main lake, and would afford ample room for suitable terminals.

On the lower Scioto, south of Columbus, other tributaries come in, upon which, according to the maps of the Topographic Survey, there are favorable sites for either storage or impeding dams. Some of these have been marked on Map No. 1 in pocket, together with easily available capacities of reservoirs. But no examination of these has been made on the ground, and not all the possibilities shown on the Topographic Survey maps have been studied in the office. From such office studies as have been made of those indicated on Map No. 1 in pocket, it would seem

that the reservoirs on Paint Creek could be used profitably for both flood prevention and power development, while that on Deer Creek could perhaps best be an impeding or detention basin. Salt Creek Valley affords opportunity for cheaply storing a large quantity of water to be held either temporarily or longer in storage, by a dam with suitable controlling gates. All of these lower reservoirs if ultimately built, can contribute materially to a navigable Scioto and mitigation of floods in its valley, which from Columbus to Portsmouth, is the richest agriculturally of any in the State.

This remarkable valley deserves protection for its future intensive farming possibilities, if not for its present worth. It is the most striking valley in the State, extending between the hills like a level floor of rich black soil almost uniformly two miles wide for a hundred miles from Columbus to Portsmouth where it terminates as suddenly as it begins. As shown in Figure 13 it was the preglacial valley of the old north-flowing Ohio, now occupied by the much smaller south-flowing Scioto. At the northern end the greater stream, which originally carved the valley, took a course which is shrouded in geological mystery by the great blanket of glacial drift covering more than half of the State as shown in the figure.

Figure 12 showed the position of Ohio with regard to the greatest known coal and ore bodies in the world, and with regard to our northern and southern water doors—the Great Lakes and Ohio River—and waterway systems connected thereto. The accompanying cut, Figure 16, shows the commercial relation of the Scioto-Sandusky route (marked Route 3 on the chart) with regard to our water outlets and coal and ore bodies. This chart deserves attention.

It was drawn upon the assumption of barge speeds of six miles per hour in open water of lakes and resevoirs; four miles in canals; five miles in slack-watered upstate streams; five miles downstream on Ohio River and three miles per hour up-stream on that river. The latter figure is due to assumed current in the canalized Ohio. If this current is reduced as is expected, one advantage of Route 3 will be increased over that shown on the chart. Time of lockage assumed to be two minutes per foot of lift. These speeds are closely in accordance with the findings of the U. S. Towboat Board already referred to.

Upon these assumptions, which display the relative speeds which would closely obtain in actual operation, it will be seen that Route 3 has noteworthy advantages in the transportation of water-borne freight between the greatest coal and ore regions of the country. The West Virginia and eastern Kentucky coal fields, which are tributary to the Great Kanawha and Big Sandy (see Figure 12), are becoming increasingly important because of their thick seams of high grade coal. The central route, Route 3, affords quickest time of passage fcr this coal to its greatest market, the

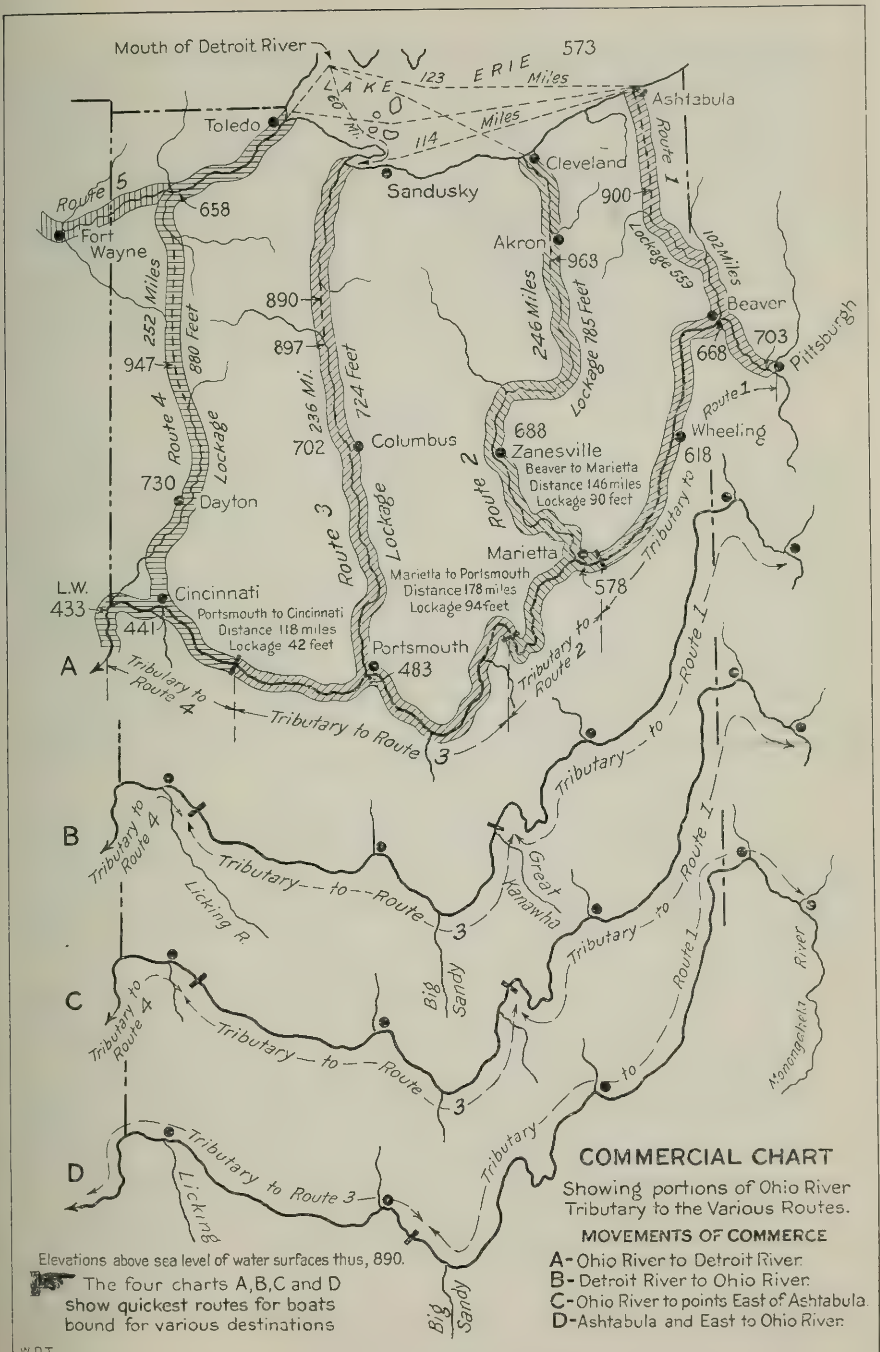

Mouth of Detroit River
LAKE ERIE
573
123 Miles
114 Miles
Ashtabula
Toledo
Sandusky
Cleveland
Route 5
658
Fort Wayne
900
Route 1
Akron
963
102 Miles
Lockage 559
252 Miles
880 Feet
890
897
236 Mi.
724 Feet
246 Miles
Lockage 785 Feet
Beaver
703
668
Pittsburgh
947
Route 4
Lockage
Route 1
688
Wheeling
Columbus
702
Zanesville
618
730
Dayton
Route 3
Lockage
Route 2
Beaver to Marietta
Distance 146 miles
Lockage 90 feet
Marietta
Tributary to Route 1
L.W.
433
Cincinnati
441
Marietta to Portsmouth
Distance 178 miles
Lockage 94 feet
578
Portsmouth to Cincinnati
Distance 118 miles
Lockage 42 feet
Portsmouth
483
Tributary to Route 2
A
Tributary to Route 4
Tributary to Route 3
B
Tributary to Route 4
Tributary to Route 3
Tributary to Route 1
Great Kanawha
Licking R.
Big Sandy
C
Tributary to Route 4
Tributary to Route 3
Tributary to Route 1
River
Monongahela
D
Tributary to Route 3
Licking
Tributary to Route 1
Big Sandy
COMMERCIAL CHART
Showing portions of Ohio River Tributary to the Various Routes.
MOVEMENTS OF COMMERCE
A-Ohio River to Detroit River.
B-Detroit River to Ohio River.
C-Ohio River to points East of Ashtabula.
D-Ashtabula and East to Ohio River.
Elevations above sea level of water surfaces thus, 890.
The four charts A,B,C and D show quickest routes for boats bound for various destinations
W.D.T.

Figure 16

north and northwest, and quickest time for ore to Ohio River regions mentioned. Other advantages of Route 3, aside from its advantage of being geographically central to Ohio, will be apparent from a study of the chart.

That traffic is increasing between the Great Kanawha and Big Sandy coal regions and the Northwest is evident from the heavy increase in such traffic on the Norfolk and Western, which extends up the Scioto Valley to Columbus, and from the new railroad now building up the valley from Ohio River to Columbus—the Chesapeake and Ohio Northern—at an estimated cost of very closely $10,000,000 for the 94 miles from Sciotoville to Columbus, this cost including a million-dollar bridge across the Ohio at the former point.

Cost and Benefits

Cost. Data is not at hand for making an estimate of the cost of the ultimate project complete, but it is thought that it should not, at the most, exceed $30,000,000, exclusive of the summit level project. This would include cost of (1) flood protection of entire Sandusky Valley to Lake Erie by construction of Reservoir **A**; (2) flood protection for Scioto Valley to nearly Portsmouth* by construction of reservoirs on Deer, Paint and Salt Creeks; (3) development of power on the streams treated both north and south of the divide; (4) construction of a 236-mile 10-foot waterway (9 foot on sills) across the center of the State; (5) combined rail and water terminals at all cities on the route from Portsmouth to Sandusky, including both of the latter.

Portions of the ultimate project would be constructed as needed. Some parts might not be needed for twenty years or more, such as completed terminals at some points. But ample lands for such terminals should be secured early, as determined by comprehensive survey of the whole situation.

If it be objected that the contemplated future expenditure is large it should be answered that our industrial future is large or small, according to our action now. New York State is expending $120,000,000† on a waterway which is intended to benefit transportation alone, except for securing some additional water power. If New York has, since 1903, expended $120,000,000 or more, why should we not be willing to expend $100,000 or such portion thereof as is necessary for an examination of an ultimate project costing one-third, and having apparently benefits exceeding in all directions those of the Erie Barge Canal, as follows:

*Floods of the Ohio will extend some distance up the Scioto Valley, and, therefore, protection for the Scioto Valley complete cannot be obtained by treatment of the latter stream alone.

†This amount is about that expended and to be expended on the Erie Barge Canal alone. The total expenditure for completion of all barge canal projects in the State will run more nearly $160,000,000.

Benefits. (1) A waterway costing one-third less per mile and having greater transporting capacity than the completed Erie Barge Canal; (2) lying directly on the route between the two greatest known ore and coal deposits in the world; (3) protecting from floods a far more valuable agricultural region than does the New York project;* (4) securing necessary flood protection to all cities thruout its 236 miles of length; (5) securing, for the future, water supplies for industrial and municipal purposes to all communities along the way, which otherwise will be at much ultimate expense for such supply; (6) creating inland lakes which will greatly add to the pleasure and other miscellaneous uses which have already been listed.

If we assume the waterway to be worth for transportation as much as a first-class railroad, or $100,000 per mile (and our discussion of the possibilities of future transportation on water justifies the belief), then the 236-mile ultimate project would be worth $23,600,000 for this purpose alone. From the last paragraph of Appendix M we believe the value of the ultimate project to farm lands alone will exceed one million dollars. Flood protection to the cities between Portsmouth and Sandusky should be worth ultimately $15,000,000. The value of water power along the ultimate route should reach $5,000,000. Water made available for municipal and industrial uses should exceed one million in value. The saving in bridges to railroads and counties (see Map No. 4) in combined future maintenance, and saving in future construction, should be worth one million or more. In addition, the value of all other miscellaneous purposes served, remains to be computed and added.

The foregoing estimate of the value of benefits from a comprehensive ultimate project is by no means accurate and complete, nor is it maintained that the ultimate project exactly as outlined in preceding pages is absolutely the best that can be devised. The example is given to emphasize the importance of treating streams for all benefits (rather than for just one) as contended for thruout this paper, and to show the necessity for an examination and survey on a comprehensive scale.

*The Mohawk Valley is not secure from floods such as that of 1913 and does not compare in extent and richness of soil with the combined lower Scioto Valley and flats west of Marion.

CHAPTER IX

A STATE-WIDE SURVEY

Such examination, survey and report as has just been proposed, for the two streams used for an example, should be extended promptly to all the main streams of the State—the Maumee and Miami, the Cuyahoga and Muskingum, the Mahoning, and such other streams as necessity shall dictate. We are far behind all other States of equal rank in the study of our water resources.

Briefest mention will make the last statement clear. New York's Water Supply Commission and its successor, the Conservation Commission has published a valuable series of reports, beginning with 1905. They treat chiefly of the regulation of their streams for water power, for industrial and municipal supply, and for flood mitigation.

The Pennsylvania Water Supply Commisson was organized in 1907, and has dealt largely with power development, flood mitigation, and encroachment upon natural stream channels. It has especially been concerned with bridge clearances over streams. There is no such supervision of bridge clearances in Ohio, and in this State often less waterway is provided under a bridge than under those farther up the stream.

Conservation Commissions have been at work on surface water resources in Minnesota, Iowa, Wisconsin, Michigan, and many other states, and Indiana has recently provided for a state flood commission.

Illinois, thru its Rivers and Lakes Commission, has been at work for seven or eight years upon the streams of that State, in cooperation with the Water Resources branch of the U. S. Geological Survey and with other organizations. It has dealt with water power, transportation, sanitation, reclamation of wet lands in rich agricultural valleys subject to floods, and with other benefits to be derived from proper stream improvement. One paragraph from the Illinois commission's 1911 report upon Kaskaskia River Valley, relates the usual trouble and we quote it in conclusion:

> "The force of these physical laws is apparent, but everyone who has had to do with drainage developments in Illinois has encountered the difficulties produced by the divided jurisdictions of disconnected, often antagonistic, drainage districts in the same watershed. These have been developed without any regard for the drainage problem of the watershed in its entirety, and often without just regard for the rights of other districts in the same watershed. The physical laws have been defined and they are absolute. The present difficulty seems to lie in the artificial laws. They have apparently developed in the same disorderly progress as the drainage developments. They have been amended and

> added to from time to time to meet new phases and conditions of drainage development until they have become so voluminous that it is inconvenient and even difficult for engineers and commissioners to follow them without making mistakes. Not only this, but *they are inadequate to meet the conditions imposed by the broader and more comprehensive scale of development herewith proposed.*"

We have italicized a portion of the above quotation to show that the trouble is always with too narrow plans, too limited a vision, and that Ohio should profit by the experience of other States. Even a local State Commission is apt to take too narrow a view of the State problems, and to secure the passage of laws of too narrow application, interfering with the wise ultimate development of the commonwealth (or its districts) as a whole.

Before organizing such a commission for Ohio, we should obtain at the outset such a broad and comprehensive view of our surface-water problems that mistakes from too limited a vision in projecting local improvements will in future be rendered improbable if not impossible. For securing such a comprehensive view the writer knows of no better plan than to call in the assistance of competent Government Officials who have made *life-time studies from the broadest standpoint of stream improvement projects;* in other words, by the passage of such legislation as is proposed in Appendix F.

The intended limits of this paper have already been exceeded, or it would be shown how one region has already suffered heavy economic loss from development of plans too narrow. The preceding chapter, it is hoped, will save the central region of the State from making the same mistake.

As a people, we are seemingly prone to short-sightedness and accompanying high cost of living. We are educated to look at but few problems from the standpoint of 50 years in future. The 1913 flood has added one more to the list. But mitigating floods for such a period is only part and not the largest of stream improvement problems. Fifty years should not be long in the life of a State or of any considerable portion of it.

On the foresight of its citizens depends the future greatness of a commonwealth. In area, population, natural resources, commercial and political position, Ohio compares not unfavorably with Holland, which, with little natural resource besides sand and salt water, has developed industry, commerce, art, education, and all that makes for civilization, to an extent surpassed by only three nations in Europe. The natural resource of Holland has been the Dutchman.

CHAPTER X

APPENDIXES

APPENDIX A

Maps In Pocket

Map No. 1, showing principal streams, watersheds, canal system, cities, dams and reservoirs existing and proposed in the State, was traced from that published in the 1898 Public Water Supply Report of the Ohio Board of Health, the original of which was prepared by the writer from Warner and Footes 1883 map of Ohio.

Some corrections have been made from the Topographic Survey maps, but since these are not all yet available, a more accurate "water map" will have to await completion of the latter survey. The State Board of Health has in preparation such a correct map of the State showing cities with reference to tributary watersheds.

The canal system was taken from the Chittenden Report and brought up to date from information furnished by the Superintendent of State Public Works. Ohio River dams are plotted from the 1908 report on Ohio River by Army Engineers and from recent information representing the situation to date. Population of cities from the 1910 United States Census.

Map No. 2, showing summit-level area of the Sandusky and Scioto Rivers and vicinity, was traced from maps of the Ohio Topographic Survey, and photographed down to half the scale. Owing to the reduction it was not possible to show all the contour lines as they appear upon the originals. The reproduction, however, shows clearly the great storage possibilities on the Sandusky as contrasted with those on the Scioto and Olentangy Rivers.

Those interested should procure the maps of the Topographic Survey and paste them together, thus obtaining a detailed map of the situation.

The latter maps show elevations by ten-foot contour lines to a horizontal scale of one mile per inch and have been made by the Topographic Branch of the United States Geological Survey in cooperation with Ohio. These maps are in sheets (about 15 by 20 inches in size) each covering 15 minutes of latitude and longitude and they may be obtained from The Director, U. S. Geological Survey, Washington D. C., for ten cents per sheet, by naming the latitude and longitude of the southeast corner of the quadrangle (sheet) desired. Within a year the entire State will be surveyed, and maps of any portion may be thus obtained. If 100 maps are ordered at a time the price is six cents per sheet.

Map No. 3, showing transportation routes of the world, was traced from that in the 1908 report on Ohio River by Army Engineers, and has been brought up to date by using maps of the U. S. National Geographic Society, the Royal Geographic Society of Great Britain since 1910, and charts of the U. S. Hydrographic Office.

The scale of the map is too small to permit railroads in thickly settled regions to be shown correctly. Those in sparsely settled regions have, however, been drawn carefully. (Those in Canada are from the 1912 map published by the Canadian Inte-

rior Department with later corrections.) Mercator's projection to which the map i drawn greatly exaggerates the size of those regions more than 40° or 50° away from the equator.

Caravan routes vary widely on the different maps and commercial atlases con sulted, and accuracy is not claimed for them. Sailing routes between the same ports vary with times of the year, and also for low-powered, full-powered, and ships under sail. Therefore, the distances from anchorage to anchorage given on the map in pocket are generalized for full-powered vessels.

Map No. 4, showing damage to bridges by the flood of March, 1913, was prepared by J. R. Chamberlin in charge of the bridge department under State Highway Commissioner, J. R. Marker. Letters were sent to county officials asking for an estimate of losses in each county and the map was drawn from this data within a week or ten days after the flood, for presentation to the legislature.

No great accuracy is, therefore, claimed for the map, but the dots (each one representing $1,000 loss in *county* bridges alone) plainly indicate the paths of the main streams of the State (except the Maumee, see paragraph 2 page 4), and suggest strikingly one benefit of stream regulation that has not been touched upon at length in preceding pages.

The total bridge loss returned by the county officials of the State was nearly $8,500,000, not including municipal and railway bridges nor highways. A similar map prepared by Professor J. Warren Smi.h for Bulletin Z of the U. S. Weather Bureau, places the total highway and bridge loss together, from the same flood, at a little over $12,000,000.

APPENDIX B

Ohio Drainage Areas in Relation to Urban Population

From Report of Ohio State Board of Health, 1898

PLACE	Serial No. order of size, 1890	Population in 1900	STREAM	Area of Watershed, Square Miles	Square Miles of Watershed per 1000 Population	Water and Sewers
Salem	48	8,267	No streams having measurable areas shown on map.	.....	....	WS
Bowling Green	77	7,810		.....	..	WS
Van Wert	52	7,448		.....	..	W
Bellefontaine	69	4,507		....	..	W
Bellevue	87	4,295		.....	....	W
Ashland	74	4,233			....	W
Barnesville	83	4,224		....	......	
Hillsboro	71	4,052		.....	..	W
Ravenna	78	3,587		......	....	WS
Bryan	86	3,189		......	....	WS
East Palestine	112	3,150		......	....	W
Leetonia	94	3,129		....	..	W
Corning	118	2,500		.....		WS
Clyde	104	2,275		......	....	WS
Orrville	113	2,162		....	.....	W
Wadsworth	117	2,032		....	.....	WS
Cadiz	114	1,923		...	...	W
Madisonville	106	3,848	Creek	5	1 3	WS
Akron	8	46,132	Creek	66	1.43	WS
			(Cuyahoga, 3 miles below)	*409*	*8.85*	
Xenia	36	7,587	Creek	12	1 6	WS
			(Little Miami, 3 miles below)	*251*	*33 0*	
Hicksville	107	3,782	Creek	7	1.85	W
Oberlin	65	5,907	Plumb Creek	12	2 03	WS
Canton	9	55,952	Nimishillen Creek	115	2 05	WS
Mansfield	16	18,410	Mansfield Creek	39	2.12	WS
Shawnee	80	3,850	Monday Creek	12	3.1	
Fostoria	39	10,000	East Branch Portage River	32	3.2	WS
Springfield	7	49,073	Buck Creek	158	3 22	WS
			(Mad River, 3 miles below)	*456*	*9.3*	
Galion	43	7,102	Olentangy River	29	4.1	WS
Lima	14	25,000	Ottawa River	114	4 6	WS
London	79	3,578	Creek	18	5.0	WS
Eaton	91	4,017	Seven Mile Creek	22	5.5	W
Wellston	64	8,000	Little Racoon Creek	47	5.87	WS *partial 2 outlets*
Marion	27	17,783	Little Scioto, 5 miles below	109	6.15	WS
			(Scioto, 7 miles below)	*536*	*30.0*	
Lebanon	88	3,442	Creek	22	6.4	W
Lancaster	35	8,390	Hocking River	54	6.45	WS
Alliance	33	12,483	Mahoning River	82	6 60	WS
Crestline	92	3,500	Sandusky River, 2 miles below	23	6.6	W
Jackson	67	6,177	Salt Creek	43	7.0	
Wilmington	85	3,454	(Todds Fork, 4 miles below)	25	7.3	
Carey	116	2,244	Creek	21	9.5	W
Delphos	60	5,347	Jennings Creek	52	9.8	WS
Norwalk	37	9,076	Huron River	94	10.4	WS
Bucyrus	45	9,306	Sandusky River	98	10.5	WS
Salineville	103	2,438	Yellow Creek	26	10.7	W
Columbus	3	150,452	Scioto River, Alum Creek	1,784	11.9	WS
Reading, Lockland and Hartwell	34	9,387	Mill Creek	120	12.8	WS

PLACE	Serial No. Order of Size, 1880.	Population 1890	STREAM	Area Watershed, Square miles	Square Miles Watershed per 1,000 Population	Water and Sewers
North Baltimore	93	5,000	Middle Branch Portage	67	13	WS
Youngstown	6	71,420	Mahoning River	967	13	WS
Washington C. H.	49	8,681	Paint Creek	120	13	WS
Greenville	53	8,474	Green Creek	119	14	W
Findlay	11	20,000	Blanchard River	322	16	WS
Shelby	109	2,089	Black Fork	37	17	WS
Marysville	95	3,831	Mill Creek	70	18	WS
St. Marys	89	5,158	St. Marys River	99	19	W
Kenton	51	7,838	Scioto River	153	19	WS
Minerva	120	2,296	Sandy Creek	47	21	W
Celina	98	5,424	Beaver Creek	130	24	W
Urbana	42	6,779	Spring Creek, 2 miles away	166	25	W
Newark	15	21,210	Licking River	525	25	WS
Wapakoneta	72	4,728	Auglaize River	128	27	W
Dayton	5	96,899	Great Miami River	2,606	27	WS
Wooster	47	5,963	Killbuck Creek, 2 miles below	172	29	W
Massillon	23	14,899	Tuscarawas River	471	32	WS
Mt. Vernon	44	6,920	Owl Creek	250	36	WS
Lisbon	105	2,554	Middle Fork Beaver Creek	98	38	WS
Delaware	30	9,810	Olentangy River	422	43	W3PrS
Oxford	111	2,119	Four Mile Creek	96	45	W
Toledo	4	132,260	Maumee River	6,615	50	WS
Elyria	50	6,591	Black River	405	61	WS
Piqua	25	13,699	Great Miami	878	64	WS
Urichsville-Den'son	40	10,927	Stillwater River	738	68	WS
Cambridge	66	6,957	Wills Creek	455	69	W
Tiffin	22	14,807	Sandusky River	1,042	70	WS
Warren	46	8,057	Mahoning River	596	74	WS
Painesville & Sub's	57	9,000	Grand River	670	74	WS
Upper Sandusky	73	3,604	Sandusky River	290	80	WS
Kent	75	3,704	Cuyahoga River	315	85	W
Nelsonville	59	6,712	Hocking River	572	85	WS
Greenfield	102	2,876	Paint Creek	247	86	W
Sidney	56	6,153	Great Miami River	561	91	W
Logan	84	3,649	Hocking River	520	143	WS
Hamilton	13	25,458	Great Miami River	3,652	144	WS
Niles	68	4,742	Mahoning River	815	172	WS
Troy	63	5,311	Great Miami River	931	175	W
Millersburg	110	2,038	Killbuck Creek	391	193	W
Montpelier	119	2,500	St. Joseph's River	530	212	WS
Fremont	38	6,029	Sandusky River	1,283	213	WS
Cincinnati	1	345,511	Ohio River	75,700	219	WS
New Philadelphia	61	6,468	Tuscarawas River	1,446	223	WS
Middletown	32	13,009	Great Miami River	3,164	244	WS
Zanesville	10	24,367	Muskingum River	6,639	272	WS
Chillicothe	19	11,646	Scioto River	3,755	322	WS
Athens	99	2,794	Hocking River	919	330	WS
Canal Dover	76	3,453	Tuscarawas River	1,401	405	W
Circleville	41	7,109	Scioto River	3,160	445	WS
Defiance	31	10,021	Maumee River	5,680	566	WS
Miamisburg	90	4,501	Great Miami River	2,735	607	
Harrison	115	1,831	White Water River	1,350	740	W
Franklin	97	3,123	Great Miami River	2,753	880	WS
Coshocton	70	4,430	Muskingum River	4,370	1,070	W
East Liverpool	20	21,558	Ohio River	23,330	1,080	WS

PLACE	Serial No. Order of Size —	Population 1880	STREAM	Area Watershed Square Miles	Square Mile Watershed Per 1,000 Population	Water and Sewers
Steubenville	17	14,833	Ohio River	23,710	1,600	WS
Bridgeport and.... Martins Ferry ..	28	14,968	Ohio River	24,400	1,630	WS
Bellaire	24	12,297	Ohio River	24,800	2,020	WS
Marietta.....	29	15,000	Ohio River	26,730	2,300	WS
Napoleon	96	2,520	Maumee River	5,820	2,309	WS
Wellsville.....	54	8,153	Ohio River	23,350	2,880	W
Portsmouth.....	18	18,000	Ohio River	61,156	3,750	WS
Ironton.....	21	13,511	Ohio River	60,000	4,450	WS
Toronto	100	5,000	Ohio River	23,680	4,700	WS
Pomeroy	58	3,963	Ohio River	28,900	9,800	W
Gallipolis	62	4,598	Ohio River	51,500	11,200	W
Middleport	82	3,432	Ohio River	38,900	11,400	
Ripley.....	101	2,422	Ohio River	68,700	28,500	WS
Cleveland	2	426,517	Lake Erie	.....	.....	WS
Sandusky	12	21,541	Lake Erie	.....	.....	WS
Ashtabula	26	15,642	Lake Erie	.....	....	WS
Lorain	55	14,827	Lake Erie	.....	.....	WS
Conneaut.....	81	8,363	Lake Erie	.....	.....	WS
Port Clinton	108	2,624	Lake Erie	.....	.....	WS

W indicates a public water supply, S that sewers more or less extensive are in use.

MIAMI CONSERVANCY DISTRICT*

DAM	Acre Feet Impounded	Dam Hight	Tributary Drainage Area	Cost of Storage Per Acre Foot	Flood Crest Reduced To
Taylorsville.....	219,400	77 ft.	1,136 square miles	$ 15 50	.....
Englewood	303,000	115 ft.	651 square miles	8 80	.....
Lockington	78,800	75 ft.	225 square miles	12 80	.....
Harshman	.....	.....	.....	.....	.....
Germantown.....	105,000	105 ft.	270 square miles	7 10	.....

*Preliminary figures, subject to change.

APPENDIX C

Subsidies to Railroads

By C. O. Ruggles, Professor of Economics
The Ohio State University

The following facts taken principally from Ripley's "Railroads, Rates and Regulation", give in a general way the amount of public aid to railroads. The total land grants by state and federal governments in aid of railroads are approximately 155,000,000 acres or 242,000 square miles. The area of the German empire is about 208,000 square miles and the area of France about 204,000 square miles. By the federal government alone some 26,000,000 acres or 40,000 square miles were given away, which amount equals about two-thirds of the area of New England States or five times the State of Massachusetts.

Aid in the form of funds or credit is very difficult to determine, but Miss Ethel Jenney, of Radcliffe College, under the guidance of Professor Hart, has given the most reliable estimates.

AMOUNTS GRANTED TO RAILROADS

Alabama	$ 15,800,000
Arkansas	7,100,000
Delaware	600,000
Florida	4,000,000
Georgia	4,000,000
Illinois	12,000,000
Indiana	1,800,000
Kentucky	200,000
Louisiana	7,700,000
Maryland	6,800,000
Massachusetts	41,000,000
Michigan	3,200,000
Minnesota	2,200,000
Missouri	31,700,000
New York	5,400,000
North Carolina	11,400,000
Ohio	500,000
Pennsylvania	12,700,000
South Carolina	5,700,000
Tennessee	34,100,000
Texas	4,800,000
Virginia	15,400,000
Total (approximately)	$228,500,000

United Sates:

Bonds	$ 64,600,000
Interest to 1887	114,000,000
	$400,000,000
Municipal and local	300,000,000
	$700,000,000

The Federal aid to the Pacific roads is shown in the following table:

Federal Aid to Railroads

	Bonds	Lands ($1.25 per acre)
Union Pacific	$27,200,000	$14,100,000
Kansas Pacific	6,300,000	7,500,000
Central Branch (U. P.)	1,600,000	278,000
Sioux City & Pacific	1,620,000	54,000
Central Pacific	25,800,000	10,000,000
Western Pacific	1,970,000	567,000
	$64,623,000	$32,536,000

Seven western states including Minnesota, Iowa, and Wisconsin gave away from one-fifth to one-fourth of their territory. The State of Texas gave away some 8,000,000 acres more than it possessed.

Facts concerning local and municipal aid are extremely difficult to secure. Special studies indicate that Baltimore gave $3,500,000, Cincinnati $10,000,000, and that the small place of Watertown, Wisconsin, with a population of about 7,500 gave $750,000 or about $100.00 per capita. Some very interesting facts are given concerning local and individual aid in senior and master's theses in the library of the University of Wisconsin.

Ripley cites instances from Potts and Stickney to show that a true estimate of the proportions of this public aid must recognize that many of the grants possessed only a nominal value. Potts, in his study of Texas, points out that a road was willing to sell 588,000 acres of land which had been given to it, for sixteen cents an acre, and Stickney cites the case of a Minnesota half-breed member of the legislature who took ten dollars in cash for his vote on a railroad bond subsidy rather than $100,000 in capital stock.

Some of the important references on Federal. State, and Municipal aid are:

I—Federal:

Donaldson, T. W.—The Public Domain, Washington Government print, 1884.
Pacific Railroad Commission Report: 50th Cong. 1st Sess., Exec. Doc. 51, 9 volumes.
Sanborn, J. B.—Congressional Grants of Land in aid of Railways, Bulletin of the University of Wisconsin, 1899.
Smalley E. V.—History of the Northern Pacific, 1883.
White H. K.—History of the Union Pacific, 1895.
Meyer H. R.—in Quartely Journal of Economics XIII, 1899, pp. 427-444.

II—State:

Wisconsin, B. H. Meyer,—Bulletin of the University of Wisconsin XII, 1892.
Texas, C. S. Potts,—Bulletin of University of Texas, No. 119, 1909.
Missouri, J. W. Million,—University of Chicago, 1896.
Michigan, H. E. Keith,—University of Michigan, 1900.
Southern States, U. B. Phillips,—History of Transportation, etc., 10, 1908.
Pennsylvania, A. L. Bishop,—The State Works of Pennsylvania, 1907.
Illinois, Davidson and Struve,—History, etc.
Nebraska, Quarterly Journal of Economics VI, p. 337 et. seq.

III—Municipal:

Hallender, J. H.—On The Cincinnati Southern.
Municipal aid in Massachusetts, 2nd Ann. Rep. Mass. R. R. Com.

The Catalog of the Bureau of Railway Economics, 1912, is valuable.

APPENDIX D

General Data From 1914 Report

Municipal Light and Power Plant, Holland, Michigan

Population of town for year of report	(31)	11,100
Station rating (installation)	(31)	1,800 K. W.
Past cost (total investment)	(27)	$249,634 26
Present value of plant	(27)	139,760 13
Investment per kilowatt of rating	(21)	138 50
Subdivided as follows:		
Plant equipment per K. W. of rating	(12)	$59 12
Distribution per K. W. of rating	(12)	69 53
Buildings per K. W. of rating	(12)	8 40
Land (low) per K. W. of rating	(12)	0 56
Miscl. equip. per K. W. of rating	(12)	
Total number of consumers	....	2,412
Total K. W. hours on switchboard	(34)	2,416,652
Total K. W. hours on consumers meters	(34)	2,094,076
Total connected load in kilowatts	(32)	4,333,591
Cost per K. W. hour on switchboard, cents	(35)	2 24
Cost per K. W. hour on consumers' meters	(35)	2 59

OPERATING COSTS FROM THE HOLLAND REPORT

Items	Description		Total Cost Per Year	Per K. W. Hour on Switchboard
1	Fuel	(26)	$17,792 13	¢0 739
2	Boiler room labor	(26)	2,195 77	0 091
3	Miscl. B. room Exp. and supplies	(26)	156 46	0 006
4	Maintenance	(26)	96 21	0 004
5	Superintendent	(24)	750 00	0 031
6	Engine room labor	(24)	2,042 56	0 085
7	Lubricants	(24)	202 14	0 008
8	Miscl. Engine room and supplies	(24)	241 00	0 010
9	Maintenance of Power Plant	(25)	595 28	0 025
10	Distribution	(25)	2,576 01	0 106
11	Consumption	(25)	4,268 59	0 176
12	Commercial	(25)	1,067 32	0 044
13	General	(25)	3,249 52	0 134
14	Undistributed	(26)	1,534 08	0 064
15	Taxes	(35)	2,008 90	0 083
16	Interest	(35)	2,187 50	0 090
17	Depreciation	(27)	13,102 64	0 544
18	Total Cost		$54,246 11	¢2 240

Figures in parenthesis refer to pages in Holland Report.

APPENDIX E

Historical and Descriptive Facts Relating to Ohio Canals

From the Chittenden Report of 1895. (*From Inception to 1895*)

	Miami and Erie Canal*			
	Miami Canal (from Cincinnati to Dayton)	Miami extension Canal (from Dayton to Junction)	Wabash and Erie Canal (from Junction to Toledo)	Ohio Canal (from Cleveland to Portsmouth)
Acts of Congress and of State legislatures providing for the construction of canals.	Ohio legislature, Feb. 4, 1825; Congress, May 24, 1828.	Congress May 24, 1828; legislature, Dec. 31, 1831.	Congress, Mar. 26, 1824; Mar. 2, 1827; May 24, 1828; Ohio legislature, Jan. 27, 1834; Indiana legislature, Feb. 1, 1834; Ohio legislature, Mar. 3, 1834.	Ohio legislature, Feb. 4, 1825; Congress, May 24, 1828.
Construction, when commenced (inclusive dates).	1825-1827	1833-1839	1837	1825-1829.
Construction, when completed (inclusive dates).	1827-1828; Cincinnati terminal, 1834.	1837-1845	1842	1827-1832; Portsmouth terminal, 1834.
Length	67.11 miles	114 miles	67 75 miles	309.
Cross section:				
Top	40 feet	50 feet	60 feet	40 feet.
Bottom	26 feet	36 feet	46 feet	26 feet.
Depth	4 feet	5 feet	6 feet	4 feet.
Distances	Lake to north end Loramie summit, 124.75 miles; summit level, 24 miles; south end Loramie summit to river, 100 11 miles; total, 248 86 miles.			Lake to north end Portage summit, 38 miles; summit level, 9 miles; south end summit level to north end bottom level, 98 miles; bottom level, 4.5 miles; south end bottom level to north end Licking summit, 39 miles; summit level, 4.7 miles; south end Licking summit to river, 115 miles; total, 308.2 miles.
Lift locks and lockage.	Lake to summit: locks, 50; lockage, 374 feet. South of summit; locks, 53; lockage, 516 feet. Total locks, 103; total lockage, 890 feet.			Lake to summit: locks, 42; lockage 395 feet. Summit to Dresden Junction: locks, 30; lockage, 238 feet. Dresden Junction to Licking summit: locks, 19; lockage, 160 feet. Licking summit to Portsmouth: locks, 54; lockage, 413 feet. Total locks, 145; total lockage, 1,206 feet.
Dimensions of locks	90 by 15 feet			90 by 15 feet.
Summit elevations.	Loramie summit: Above Lake Erie, 374 feet; above Ohio River, 516 feet.			Portage summit: Above Lake Erie, 395 feet; above Ohio River at Portsmouth, 492 feet; above Ohio River at Marietta, 398 feet.
Guard locks	3			11.
Aqueducts	19			16.
Reservoirs	Six Mile, in Paulding County; Grand in Mercer County; Loramie, in Shelby County; Lewiston in Logan County.			Summit, in Summit County; Licking, in Fairfield County, Licking County, Perry County.

*Name adopted by act of legislature of March 14, 1849, the canal being known previous to that time under the three following names: Miami Canal, Miami Extension Canal, and Wabash and Erie Canal.

Historical and Descriptive Facts Relating to Ohio Canals—Continued.

From the Chittenden Report of 1895. From Inception to 1895—Continued

	Miami and Erie Canal.	Ohio Canal (from Cleveland to Portsmouth).
Feeders, side-cuts, etc., included in original acts authorizing canals.	Middletown feeder, ½ mile; Dayton feeder, ⅓ mile; Hamilton side-cut, ¾ mile; Sydney feeder, 14 miles; Loramie feeder, ½ mile; Grand Reservoir feeder, 2 miles; Wabash and Erie Canal from junction to State line, 18 miles; total length, about 36 miles. Guard locks, 1; lift locks, 4; lockage, 28 feet.	Tuscarawas feeder, 3.25 miles; Walhonding feeder, 1.37 miles; Muskingum side-cut, 2.72 miles; Granville feeder, 6.17 miles; Columbus side-cut, 11.75 miles; total length, 25.26 miles. Guard locks, 1; lift locks, 7; lockage, 52 feet.
Branch canals constructed or acquired under special acts, subsequent to construction of main lines to which they are tributary.	Warren County Canal, commenced by a private company, incorporated by act of Feb. 22, 1830; it was adopted by the State as "part and parcel" of the Miami Canal by act of Feb. 9, 1836; completed in 1840; length, 17 miles; no locks; dimensions same as on Miami Canal.	Sandy and Beaver Canal, built by a private company, incorporated by act of Jan. 11, 1828; State adopted portion from Bolivar to Sandyville in 1856; length, about 6 miles; 1 lock. Walhonding and Mohican Canal authorized by act of Mar 14, 1836; commenced in 1836; completed in 1841; length, 25 miles; dimensions same as on Ohio Canal; guard locks, 2; lift locks, 11; lockage, 85 feet. Hocking Canal. A part of this canal, "Lancaster Lateral," from the Ohio Canal to the city of Lancaster, was built by a private company, incorporated by act of Feb. 8, 1826; 16 miles length below Lancaster was built by the State; commenced in 1836; completed in 1844. "Lancaster Lateral" Canal adopted by State in 1838; total length Hocking Canal, 56 miles; dimensions same as for Ohio Canal; locks, 26; lockage, 177 feet. Muskingum improvement, authorized by act of Mar. 9, 1836; commenced, 1836; completed, 1841; length, 91 miles; locks, 12 (36 by 180 feet); lockage, 125 5 feet. Total mileage of above, 178 miles.
Complete canal system of State.	301.49 miles	512 26 miles.
Cost of Ohio canals and how paid.	Miami and Erie Canal .... $8,062,680.80 Ohio Canal .... 7,904,971.89 Total .... 15,967,652.69 Cost of canals defrayed primarily by means of State loans. Extensive donations of land along the line of the canals and some cash contributions were received. The United States Government, under acts of Mar. 2, 1827, and May 24, 1828, gave certain lands to the State in aid of her canals. The State has realized from the sale of these lands down to the present time the sum of $2,257,487.32 and the estimated value of those remaining unsold is $1,250,000.	
Abandonments	In Cincinnati, 0.62 mile, act of Mar. 24, 1863; State has recovered this property. Hamilton side-cut, act of Apr. 27, 1872, 0 75 mile. Warren County Canal, 17 miles, act of Mar. 11, 1853. Wabash and Erie Canal, State line to 1 mile from junction, 17 miles, including six-mile reservoir, acts of Apr. 12, 1888, and Mar. 3, 1891. In Toledo, 3.75 miles, acts of Mar. 26, 1864. Jan. 31, 1871. Total abandonments, 39 12 miles. Remaining length of Miami and Erie system, 262.82 miles.	Hocking Canal, 56 miles, acts of Mar. 6, 1873, Apr. 11, 1878, and May 18, 1894; State has instituted action for recovery. Granville feeder, 6.17 miles, act of Apr. 11, 1876. Walhonding feeder, 1.37 miles, act of Apr. 3, 1834. Cleveland terminal, 3 miles, act of Apr. 27, 1872. Muskingum improvement, 91 miles; turned over to the United States by act of May 2, 1885. Total abandonments, 157.54 miles. Remaining length of Ohio canal system, 354.72 miles.

APPENDIX F

Proposed Legislation

81st General Assembly. }
Regular Session. }

H. B. No. 227

MR. HUNTER

A BILL

To provide for a survey, examination and report upon waterways of the state by special board.

Be it enacted by the General Assembly of the State of Ohio:

SECTION 1. That the governor is hereby authorized and directed to secure from the proper federal authorities as soon as practicable, the appointment of not more than three experienced active or retired government engineers, who, with persons to be appointed by the governor, shall constitute a board of not more than five to examine and report at the earliest practicable date to the governor, upon waterways connecting Lake Erie with the Ohio River along at least three routes across the state.

SECTION 2. *Said survey, examination and report shall have special reference to the improvement of existing stream channels for the mitigation of floods, for navigation of suitable draft, for the development of power, for the betterment of sanitary conditions, and for any allied benefits that may properly accrue to the national, state or local communities interested.*

SECTION 3. Said board shall include in their report, recommendations as to the proper proportions of the cost of such improvements, as they find feasible and advisable, to be borne by the United States, the State, and the other political communities interested.

SECTION 4. Said board shall include in their report recommendations as to the proper method or methods of financing such projects as they find feasible and advisable, and said board is hereby authorized to receive and report upon proposals for cooperation from any of the political communities or public and private parties interested.

SECTION 5. Said board or its employees or agents are hereby authorized to examine or survey public and private property, and are hereby given access to all public records, so for as the same may be necessary to carry out the provisions of this act.

SECTION 6. The compensation of the members of the board, unless otherwise provided for, shall be determined by the governor. Said special board shall have charge of the employment of all assistants, and shall fix compensation of all its employees.

SECTION 7. There is hereby appropriated out of any moneys in the state treasury to the credit of the general revenue fund not otherwise appropriated, the sum of one hundred thousand dollars for carrying out the foregoing provisions.

Senate Joint Resolution

Proposed to committee April, 1913

Resolved, That the senators and representatives from the State of Ohio in congress, be requested to use every honorable means to secure the passage thru the present congress of the United States an Act authorizing the Secretary of War to appoint a

board of three experienced active or retired members of the corps of engineers U. S. A. with an executive officer from the same corps, to examine and report upon the feasibility and advisability of constructing waterways from Lake Erie to the Ohio River along at least three routes across the state, having special reference to the improvement of existing river channels for navigation of suitable draft, to the mitigation of floods, to the development of power, and to the development of any allied benefits that may properly accrue therefrom to the State or United States, or both; and that our senators and representatives in Congress be urged to use every honorable means to secure in the passage of such an Act, an appropriation of not less than $100,000 for the purposes herein set forth, and that said board of army officers shall include in their report recommendations as to the relative proportions of the costs of such river regulations, and improvements as they find feasible and advisable, to be borne by the political communities interested, and that said board of army officers include in their report recommendations as to the proper method or methods of financing such projects as they find feasible and advisable.

APPENDIX G

Water Rates Prevailing at Various Ohio Cities

From paper by F. C. Dunlap, 1912

Cities	Population	Source of Supply	Filtered	Daily Consumption—gals.	Daily Per Capita Consumption	Number of Services	Number of Meters	Percentage Metered	Highest Meter Rate per 1000 gal.	Lowest Commercial Rate per 1000 gal.
Alliance	15,000	River	No	4,000,000	266	3,200	200	7.0	.15	.04
Ashland	7,200	Wells	No	445,214	61	1,800	1,400	100.0	.40	.086
Ashtabula	20,000	Lake	Yes	3,500,000	...	4,000	3,300	.....	.20	.10
Barberton	11,000	Wells	No	1,300,000	125	1,050	....	.....	.08	.08
Barnesville	4,500	Imp.	No	100,000	...	370	370	100.0	.50	.06
Bellefontaine	8,862	Wells	No	76,667	..	2,102	94	4.5	.10	.08
Bellevue	5,200	Imp.	No	600,000	120	1,000	.	.....	...	...
Bucyrus	8,122	Imp.	Yes	940,000	115	1,240	910	74.0	25	.08
Canal Dover	7,600	Wells	No	531,784	80	1,350	13	1.0	25	.06
Celina	3,500	Wells	No	....	...	500	25	5.0	.15	.07
Chillicothe	15,000	Wells	No	1,000,000	...	2,800	180	.....	.20	.15
Cincinnati	395,000	River	Yes	48,059,051	126	51,366	21,599	42.0	.10	.10
Circleville	6,500	Wells	No	400,000	...	1,344	200	.....	.30	.15
Cleveland	630,000	Lake	No	65,691,000	104	83,011	81,281	98.2	.053	.053
Columbus	195,000	River	Yes	14,592,000	75	27,315	25,035	92.3	.12	.106
Conneaut	9,000	Lake	Yes	1,600,000	...	2,200	900	.....	25	.06
Coshocton	10,000	Wells	No	1,200,000	120	2,400	50	2.0	.25	.05
Dayton	116,000	Wells	No	11,000,000	90	25,000	23,182	96.4	.08	08
Defiance	8,000	River	No	1,200,000	...	1,075	80	8.0	.40	.05
Delaware	10,000	Wells	No	1,000,000	65	1,800	950	55.0	.25	.07
Delphos	......	Wells	No	500,000	...	1,100	260	20.0	.20	.07
Urichsville } Dennison	8,759	Creek	Yes	1,600,000	182	1,800	1,497	76.6	.30	.06
E. Cleveland	10,000	Lake	No	1,620,000	...	3,750	2,400	.....	.20	.093
E. Palestine	4,000	Wells	No	375,000	93	800	6	.....	.25	.07
Elyria	15,000	Lake	Yes	1,750,000	...	3,400	3,400	100.0	.20	08
Findlay	15,000	Wells	No	1,100,000	73	2,500	2,500	100.0	.24	.08
Fostoria	9,597	Creek	Yes	856,000	...	1,553	1,204	70.0	.20	.07
Franklin	3,000	Wells	No	300,000	...	550	45	8.0	.15	.08
Fremont	9,939	River	No	....	...	2,021	1,397	65 3	.12	....
Gallipolis	6,500	River	Yes	400,000	...	1,014	720	75.0	...	....
Geneva	2,500	River	Yes	400,000	...	731	731	100.0	.30	.075

Cities	Population	Source of Supply	Filtered	Daily Consumption Gallons	Daily Per Capita Consumption	Number of Services	Number of Meters	Percentage Metered	Highest Meter Rate Per 1000 Gal.	Lowest Commercial Rate Per 1000 Gal.
Hicksville	2,600	Wells	No	312,600	120	380	.....	.....	25	...
Kenton	7,200	Wells	No	900,000	126	1,500	100	.....	.20	.08
Lancaster	14,000	Wells	No	800,000	60	1,670	980	60.0	.10	.05
Leetonia	2,800	Wells	No	70,000	...	600	518	.....	.333	....
Lima	30,000	River	No	3,500,000	110	5,572	1,800	33 3	.20	.08
Logan	4,500	.....	Yes	....	...	750	....	.....	.20	.10
London	3,640	Wells	No	436,959	120	700	25	3.5	.25	.06
Mansfield	23,000	Wells	No	1,500,000	60	4,400	1,350	.....	.20	.07
Marietta	15,000	River	Yes	2,500,000	150	3,000	400	17.0	30	.04
Marysville	3,576	Wells	No	515,000	144	659	37	5.6	.25	.07
Massillon	15,000	Wells	No	764,680	51	3,202	845	26.0	.20	.12
Middletown	16,000	Wells	No	2,800,000	...	2,400	1,050	41.0	.093	.064
Millersburg	2,000	Wells	No	500,000	...	400	5	.....	.06	.04
Napoleon	.....	River	No	300,000	60	699	550	98.0	.146	066
Nelsonville	7,000	Wells	No	800,000	114	950	1	.....	.10	.10
Newark	25,400	River	Yes	2,750,000	...	4,000	3,000	75.0	.20	.111
Newburgh	6,000	Lake	No	193,700	...	881	881	100.0	.173	.173
N. Philadelphia	9,500	Wells	No	1,000,000	...	1,740	160	5.0	.225	.07
Niles	9,000	River	Yes	750,000	...	1,200	100	10.0	.40	.08
Orrville	3,500	Wells	No	500,000	21	891	800	100.0	.20	.05
Oxford	2,019	Wells	No	318,206	...	545	60	11.0	.135	.09
Port Clinton	3,500	Lake	Yes	600,000	150	890	250	35.0	.10	.066
Ravenna	5,600	Wells	No	1,250,000	...	1,577	24	.....	.15	.05
Reading	4,300	Wells	No	71,752	165	350	349	100.0	.266	.066
Sandusky	20,000	Bay	Yes	5,000,000	230	4,000	3,200	.	.12	.066
Shelby	5,000	Wells	Yes	700,000	120	970	274	33.0	.25	.04
Springfield	49,000	Imp.	No	6,000,000	122	8,435	1,400	16 0	.10	.06
St. Marys	5,700	Wells	No	500,000	...	1,100	200	20.0	.10	.10
Toledo	200,000	River	Yes	16,600,000	83	24,244	19,856	80 0	.09	.06
Troy	6,122	Wells	No	800,000	97	1,500	450	30 0	.12	.06
Urbana	7,700	Wells	No	1,000,000	130	50	53	3.4	.40	.10
Van Wert	7,600	Wells	No	500,000	...	1,200	490	.....	.25	.10
Wapakoneta	5,500	Wells	No	400,000	80	....	500	70.0	.25	.06
Wauseon	2,650	Wells	No	325,000	125	722	510	70.0	25	.08
Xenia	10,000	Wells	No	497,000	...	1,700	80	.....	.25	.10
Youngstown	86,200	River	Yes	....	...	13,125	3,150	24.0	.16	.08
Zanesville	28,000	River	No	2,000,000	300	8,000	70	10.0	.06	....

APPENDIX H

Estimated Cost of Summit Level Project

By Professors R. C. Sloane and W. S. Hindman, of The Ohio State University

SUMMARY

Summit Level Reservoir with 20% Contingencies	$5,095,208 80
Summit Level Cut with 20% Contingencies	5,650,044 00
Marion Branch Canal with 20% Contingencies	782,086 80
White Sulphur Reservoir with 20% Contingencies	2,300,004 00
Columbus Improvement with 20% Contingencies	2,323,500 00
Delaware Detention Basin with 20% Contingencies	1,146,200 00
Channel and Bank improvements at Delaware with 20% Contingencies	150,000 00
Grand Total	$17,447,043 60

Itemized as follows:

RESERVOIR C

Land, 6,000 acres @ $150.00	$ 900,000 00
Dam (C), 74,320 cu. yds. concrete @ $6.00	445,920 00
Earth fill, 56,000 cu. yds. @ 25¢	14,000 00
Gates for Dam C	10,000 00
Riprap 4,500 sq. yds. @ $1.50	6,750 00
Rebuilding 26 mi. of Macadam Road @ $10,000	260,000 00
Clearing Reservoir Site	80,000 00
Warrensburg (Buying village outright)	15,000 00
New Bridge (Richwood Rd. Highway Bridge)	50,000 00
New Highway Bridge at C. M. S. & N. crossing	50,000 00
Raising C. M. S. & N. Electric Ry. bridge	5,000 00
New Highway Bridge at Warrensburg	80,000 00
	$1,916,670 00
Engineering, Legal, Interest and Contingencies 20%	383,334 00
Total	$2,300,004 00

RESERVOIR B

Summit-Level Reservoir

20,000 Acres land @ $150 (less $250,000 salvage)	$2,750,000 00
Clearing reservoir site	200,000 00
Village of Little Sandusky	80,000 00
Moving oil pumping station	100,000 00
New track Hocking Valley R. R., 9 mi. @ $30,000	270,000 00
Tearing up 5½ mi. old track @ $300.00	1,650 00
Levee south of Harpster 916,450 cu. yds. @ 20¢	183,290 00
2.6 miles macadam road @ $10,000	26,000 00
327,900 sq. ft. concrete apron on levee @ 12¢	39,348 00
1,664 rods fence @ $1.50	2,496 00
Concrete dam and spillway 69,500 cu. yds. @ $6.00	417,000 00
276,400 cu. yds. earth dam @ 25¢	69,100 00
4000 cu. yds. earth levee north of Dam C @ 20¢	800 00
16 gates 30 ft. wide	10,000 00
Cobble stone facing for earth dam 6,500 sq. yds. @ $1.50	9,750 00
160 rods fence @ $1.50	240 00
1 mile macadam road	10,000 00
Moving telephone and telegraph lines from site	12,000 00
Raising Pennsylvania Ry. at Nevada	6,000 00
5 Highway Bridges @ $20,000	100,000 00
	$4,287,674 00
Engineering, Legal, Interest and Contingencies 20%	807,534 80
Total	$5,095,208 80

Summit-Level Cut

1200 Acres land @ $150.00	$ 180,000 00
Summit level cut from Reservoir B to 1.5 miles south of Green Camp, 16,325,400 cubic yards @ 10¢	1,632,540 00
Exc. from 1½ miles south of Green Camp to 5 miles south of Prospect, 2,400,000 cubic yards Rock @ $1.00	2,400,000 00
Raising C. C. C. & St. L. R. R. tracks, 17,400 cubic yards @ 30¢	5,220 00
Ballast 4,000 feet @ .568 cubic yards per feet @ 35¢	800 00
Surfacing and laying track, 4,000 feet	1,120 00
Big 4 bridge over canal complete 350 feet span	66,800 00
Raising Erie R. R. tracks, 11,800 cubic yards @ 30¢	3,540 00
Surfacing and laying tracks, 3,400 feet	1,000 00
Ballast, 3,400 feet	680 00
Erie R. R. bridge over canal (complete)	66,800 00

Raising Hocking Valley tracks, 55,000 cubic yards @ 30¢	$ 16,500 00
Surfacing and laying track, 6,600 feet	1,850 00
Ballast 6,600 feet	1,320 00
H. V. R. R. bridge over canal (complete)	70,200 00
5 Highway Bridges over canal	200,000 00
Riprap sides of canal 56,320 square yards @ 80¢	50,000 00
Ditches	10,000 00
	$4,708,370 00
Engineering, Legal, Interest and Contingencies 20%	941,674 00
Total	$5,650,044 00

Marion Side Cut and Turning Basin

360 Acres land @ $150.00	$ 54,000 00
Excavation, 4,882,830 cu. yds. @ 10¢ (canal)	488,283 00
Excavation, 911,060 cu. yds. @ 10¢ (turning basin)	91,106 00
Diverting highway around turning basin	5,750 00
Riprapping sides of canal and basin, 17,000 sq. yds. @ 80¢	12,600 00
	$ 651,739 00
Engieeering, Legal, Interest and Contingencies 20%	130,347 80
Total	$ 782,086 80

Improvements in Columbus

Purchase of land, $15.00 per ft. front	$ 300,000 00
3 Bridges (Broad, Town and State St.) @ $100,000	300,000 00
Adding 100 ft. span to 20 bridges @ $30,000	600,000 00
Moving buildings from site	250,000 00
Excavation, 1,045,000 cu. yds. @ 45¢	460,250 00
Changing sewers and lighting systems	6,000 00
Temporary bridges	20,000 00
	$1,936,250 00
Engineering, Legal, Interest and Contingencies 20%	387,250 00
Total	$2,323,500 00

RESERVOIR A

36,000 acres farm land @ $150.00	$5,400,000 00
Clearing reservoir site	500,000 00
Excavation, 278,470 cubic yards @ 45c	125,311 50
Concrete 70,850 cubic yards @ $6.00	425,100 00
5,840 square yards paving Res. side of earth dam @ $1.50	8,760 00
Gates (16) 15′×30′ in 5′ sections	10,000 00
1 mile macadam road	10,000 00
190 rods fence @ $1.50	285 00
12 miles new track for T. & O. C. Ry. @ $30,000	360,000 00
8 miles tearing up T. & O. C. Ry. @ $300.00.	2,400 00
17¼ miles new track for Northern Ohio @ $30,000	517,500 00
Tearing up 10½ miles old track (Northern Ohio) @ $300.00	3,150 00
Buying McCutchenville (outright)	100,000 00
Moving telegraph and telephone lines	10,000 00
6 highway bridges (new) @ $20,000	120,000 00
Raising bridges at Upper Sandusky	8,000 00
7½ miles new macadam road @ $10,000	75,000 00
Raising Northern Ohio bridge at Sycamore	5,000 00
	$7,680,506 50
Engineering, Legal, Interest during Construction, Contingencies 20%	1,536,101 30
Total	$9,216,607 80

APPENDIX K

Letters Relating to Summit Level Cut

COLUMBUS, OHIO, February 8, 1915.

MR. ARTHUR S. KING, *Advertising Manager,*

The Marion Steam Shovel Company, Marion, Ohio.

MY DEAR MR. KING:

I am enclosing a map showing proposed summit level cut and proposed side-cut and turning basin in Marion. This excavation would amount to about 15,000,000 cubic yards with an average section for a distance of nine (9) miles, as shown on accompanying page. The sections shown together with the distance named does not check out to equal the 15,000,000 cubic yards, but I am asking you to assume that such would be the total amount of excavation. (Section 210 feet wide at bottom with 2 to 1 side slopes.)

At two short sections of about 1,000 ft. each the cut might run as high as 40 ft. deep·

On account of the width of the cut it would apparently be a suction dredge proposition, and I am anxious to know if your suction dredge engineer cannot give me an estimate of the cost per yard under the circumstances herein set forth. The main information I desire is whether the suction dredge could handle such material as would be encountered in making such a cut. It would likely be clay and gravel mixed, but at places it might be almost pure clay. Supposing there should be 5,000,000 yards of clay in the cut, what would be the cheapest way to handle this material, assuming it to be spoiled along the banks on each side?

Your kindness in giving me this information will be much appreciated.

Hoping to hear from you at an early date, I remain, with kindest regards,

Yours very truly,

C. E. SHERMAN.

THE MARION STEAM SHOVEL CO.

MARION, OHIO, U. S. A., February 20, 1915.

PROF. C. E. SHERMAN,

Ohio State University, Columbus, Ohio.

DEAR PROFESSOR SHERMAN:

When we received your letter of February 8th, we had no idea that it would take us so long to answer your questions or we should have notified you. We trust, however, that this unavoidable delay in replying will not have caused you any undue inconvenience.

Our engineers say that the information given is not full enough to enable them to go into the subject in detail, but they have done everything they could, and we are pleased to report their findings.

On account of the extremely large section of the proposed canal, together with the large amount of material to be removed, it would appear to be necessary to use large machinery, the type of this machinery depending somewhat on conditions. With the information at hand we are not in a position to make a definite recommendation as to what type would be best adapted, but we believe either drag line excavator or hydraulic dredge machinery could be made to do the work satisfactorily.

Our Model 281 scraper-bucket excavator would have sufficient range for making the excavation, provided machines were mounted on each side of the cut. This seems entirely practical because it would require at least four machines working twenty-four hours per day to do this work in three years. The cost of operating this type of machinery per cubic yard, as you are undoubtedly aware, depends to a considerable ex-

tent on the conditions of operation. The nature of the material to be handled and the skill of the operator are the large deciding factors. We believe, however, that one of these machines working under normal conditions, such as are described in this letter, could handle material for from 4½ to 5c per cubic yard.

One feature which is worth keeping in mind when drag line equipment is being considered, is that the machines have sufficient range of operation for making the maximum cut without any auxiliary machinery. When considering the hydraulic type of machinery one point must be kept in mind—whether or not it is possible to maintain water in the cut, and if possible, at what level the water can be held. There is no doubt whatever that a hydraulic dredge could be designed to do this work, but our experience in handling pure clay has been that it is the hardest material—aside from rock—that a machine of this class can be made to handle.

We doubt if the material can be handled with hydraulic dredges for less than 5 or 6c a yard under average conditions since a considerable length of discharge pipe must necessarily be used in order to waste the excavated material. We are not raising these objections with the idea of discouraging the use of the hydraulic dredge, but more with the idea of obtaining the necessary information to figure intelligently should you favor this class of machinery. One thing decidedly in favor of the hydraulic dredge is its very large capacity. Twenty-inch machines have been known to handle as high as 400,000 yards in one month where digging conditions were ideal.

From a study of the map, we are inclined to think that there is going to be a very long haul for coal, should steam machines be used; and although we have not gone into the matter very thoroly, it occurs to us that electric-driven machinery might be used to advantage. If this were the case, power could probably be obtained from some present plant, such as the one at Stratford, Ohio, or a temporary power plant could be installed.

In conclusion we would say that the proposition seems to be suited either to large scraper-bucket excavators—probably our Model 281 machines equipped with 5-yard buckets and 150 feet booms—or 20-inch hydraulic dredges. We believe that the drag line machines would handle the material slightly cheaper than the hydraulic dredges, but on this point we should not want to commit ourselves until we were given more data and more time to work out the problem thoroly.

We are afraid, also, that we shall be unable to answer your question as to the cheapest method of handling, say 5,000,000 yards of clay in the cut, for to do this it would be necessary to know the exact conditions existing, and of course, no one at present knows anything about them. We believe, however, we have covered the whole proposition in a general way, and if we can supplement any of the information given in this letter by more detail, we should be very glad to do so, provided sufficient information were given to enable us to make our calculations more intelligently.

The writer does not remember whether or not your files included copies of our latest catalogs, but he is forwarding today a copy of Catalog 54, describing and illustrating our shovels, and a copy of Catalog 53, which describes and illustrates our dredges.

It has certainly been a pleasure to us to work on this problem of the proposed canal, and we sincerely trust that you will give us an opportunity to be of further service to you as the occasion demands.

Yours very truly,

THE MARION STEAM SHOVEL COMPANY

ARTHUR F. KING,
Advertising Manager.

APPENDIX L

Reservoir Data

By P. O. SCHUBERT, C. E.

Data for Reservoirs Full*

Reservoir	DAM		Average Depth of Reservoir	AREA		STORAGE		COST	
	Maximum Hight in Feet	Approximate Length in Feet		Acres Flooded	Acres to be Bought	Acre Feet	Million Cu. Feet	Total	Per Acre Foot
A	60	2310	18.50	28,600	36,000	530,678	23,116.300	$9,216,607 80	$17 36–
B	71	2288	16.30	13,920	20,000	226,316	9,858.000	4,845,208 80	21 41—
C	60	1040	10.95	3,495	6,000	38,281	1.667	2,300,004 00	60 08

*Reservoir A is full at elevation 810 feet above sea level.
*Resevoirs B and C are each full at 900 feet elevation.

Reservoir Capacities at Successive Hights

Contents in Acre-feet

(One acre-foot=43,560 cubic feet)

CONTOUR INTERVAL	RES. B.	RES. C.	RES. A.	
910 to 905	*90,000	*52,730	810 to 800	229,040
905 " 900	*75,000	*41,020	800 " 790	143,000
900 " 895	62,250	*12,804	790 " 780	82,150
895 " 890	48,857	*10,804	780 " 770	45,326
890 " 885	37,274	5,000	770 " 760	22,028
885 " 880	26,873	3,925	760 " 750	7,648
880 " 870	29,576	3,904	750 " Bottom	1,600
870 " 860	13,026	1,511	.....	.....
860 " 850	5,146	330	.....	.....
850 " 840	3,034	.....	.....	.....
840 " Bottom	280	.....	.....	.....

*Interpolated.

APPENDIX M

Scioto Big Marsh Flood

July, 1915

On July 15 and 16, 1915, (after the maps and rainfall charts for this bulletin had been engraved) a heavy rain fell upon the headwaters of the Scioto and Olentangy rivers which caused far more loss to farmers than did the flood of March, 1913. The rainfall as taken from the U. S. Weather Bureau bulletin for July was as follows:

RAINFALL IN INCHES

Station	July 15	July 16
Lima (average)	1.45	4.06
Kenton	2.00	3.65
Marion	1.20	3.05
Prospect	1.90	3.00
Cardington	2.16	2.44
Delaware	.79	2.68
Average	1.58	3.15

The summer of 1915 was one of the rainiest of record, keeping the ground well saturated until the above rain fell upon it. The result was a flood which destroyed about $2,000,000 worth of crops.

The heaviest rainfall was along the upper Scioto headwaters, and on Scioto Big Marsh (between Kenton and Lima) the crop loss was reported at more than $1,000,000 in the U. S. Weather Bureau bulletin mentioned. The waters again flooded the area west of Marion (Map No. 2) to nearly the hight reached in March, 1913, but the flood loss to farmers in the affected area far exceeded that of 1913.

The flood proceeded downstream on both Scioto and Olentangy rivers, destroying by saturation the intensive crops raised on the fertile Scioto bottoms in lower Franklin, and in Pickaway and Ross Counties. The flood exhausted its violence when Pike County was reached, and the bottom lands there were not covered, the river channel being sufficient to contain the waters.

A careful estimate of the flood damage (the first of which the writer had knowledge) done by this storm is now being made, partial figures thusfar available being as follows:

County	Acres flooded	Damage
Franklin (lower portion)	4,996	$106,558
Pickaway	8,640	213,045
Ross	3,290	38,179
Total	16,926	$357,782

The loss between Columbus and Kenton was almost as heavy as that scheduled above, most of the damage occurring in the area shown on Map No. 2 (in pocket) as flooded in 1913. At the extreme headwaters of the Scioto the damage was greatest of all. This region was formerly a swamp, known as Scioto Big Marsh. But after it was drained it became one of the richest agricultural regions in the state, and is devoted to intensive farm trucking. These crops were drowned, the water raising higher at some points between Lima and Kenton than it did in 1913, it is stated.

The estimate of damage is being made by Professor J. Warren Smith of the U. S. Weather bureau for the Franklin County Conservancy District, by personal survey of the property and interview with each land owner, and by collecting such other data as is available.

The farmers of the Scioto Valley almost uniformly declared that their lands would be doubled in value by *complete* flood protection. Since this is impossible (see Chapter II), we estimate that the protection secured by plans proposed in Chapter VIII would increase the value of the lands at least 50 per cent. The bottom land from Columbus to Portsmouth averages in value more than $100 per acre, and comprises more than 100,000 acres, of which the larger portion is subject to floods.

136.

137

158

140

A

THE OHIO STATE UNIVERSITY BULLETIN

Vol. XXI JANUARY, 1917 No. 12

CONGRESS OF HUMAN ENGINEERING

October 26, 27 and 28, 1916

BULLETIN No. 16

COLLEGE OF ENGINEERING

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CONGRESS OF HUMAN ENGINEERING

UNIVERSITY HALL

OHIO STATE UNIVERSITY

COLUMBUS, OHIO

October 26, 27 and 28, 1916

THURSDAY, OCTOBER 26

11:00 A. M.—C. R. Dooley, Manager of the Education Department of the Westinghouse Electric and Manufacturing Company:
"*The Opportunities and Requirements of the Engineering Profession.*"

3:00 P. M.—D. G. Mitchell, President of Delaware College, Newark, Delaware:
"*The Timeliness of the Congress of Human Engineering.*"

4:00 P. M.—C. R. Hook, Vice President of the American Rolling Mills Company, Operation Division:
"*Human Engineering in Steel Mills.*"

8:00 P. M.—F. H. Newell, Professor of Civil Engineering of the University of Illinois:
"*The New Emphasis on the Human Factor in Industry.*"

FRIDAY, OCTOBER 27

Morning Conference 8:30 to 12:00

Peter Roberts, Industrial Department of International Committee of Y. M. C. A.:
"*Training the Foreigners Through Industries.*"

C. J. Hicks, Executive Assistant to the President of the Colorado Fuel & Iron Company:
"*Industrial Betterment Progress by the Colorado Fuel and Iron Company.*"

W. A. Grieves, Secretary of the Jeffrey Manufacturing Company:
"*The Handling of Men.*"

Afternoon Conference 1:30 to 5:00

Charles R. Towson, Industrial Department of International Committee of Y. M. C. A.:
"*The Human Factor in Industry.*"

Edwin L. Shuey, Director, Advertising Department, The Lowe Brothers Company, Dayton, Ohio:
"*Human Engineering in Welfare Work.*"

John A. Voll, President of the Ohio State Federation of Labor:
"*The Human Side of Engineering as Viewed by the Wage-Earner.*"

Joseph W. Roe, Professor of Mechanical Engineering, Yale University:
"*The College Man and Human Engineering.*"

Evening Conference 7:30 to 9:30

Captain William P. White, U. S. N. Ret., General Manager of the Lowell Paper Tube Corporation.

John P. Frey, Editor of International Molders' Journal:
"*The Human Side of the Worker.*"

SATURDAY, OCTOBER 28

Morning Conference 8:30 to 12:00

Willard Beahen, Engineer for the New York Central Railroad:
"*The Engineering of Men.*"

Fred Rindge, Jr., Industrial Department of International Committee of Y. M. C. A.:
"*New Ideals in Human Engineering.*"

L. T. Warner, Warner Brothers Company, Bridgeport, Conn.:
"*New Ideals in Human Engineering*"

Horace B. Drury, Department of Economics and Sociology of The Ohio State University:
"*Scientific Management and Progress.*"

THE

CONGRESS OF HUMAN ENGINEERING

INTRODUCTION

The amazing progress of science in all branches of engineering within the span of a short lifetime has brought into commonplace experience achievements which a few decades ago were either undreamed of or were regarded as marvels to be brought about only under special conditions and by extraordinary effort. Yet a great triumph of engineering, a new invention or a great structure is soon relegated to the scrap heap to make way for something which does the same work more efficiently. Fine structures and wonderful machines are ruthlessly demolished in order to take full advantage of the most efficient way of doing things. "Efficiency" has come to be the watchword of Industry.

This efficient application of science to engineering has given to humanity comforts and luxuries (some useful, some harmful) which could not have been obtained by common people and perhaps not even by the favored few if the old, costly methods had to be used. Naturally and properly, when the modern man found that, thru efficiency, he could make larger profits and possess more of the things which are pleasant to have he demanded more and more of efficiency everywhere. In fact a special profession, that of the efficiency expert was created. For a while, when men tried to reduce the costs of production by the application of "efficiency" they were thinking of more and better machines, of the elimination of labor by machines and even thought of training workers to be machines tending machines. The attention of industry was directed toward the production of material things and it tended to lose sight of the humanity for which these things were made. The result inevitably was that a class of industrial workers was developed whose outlook was not much better than that of the serf of the middle ages. Fortunately this happened in an age when the widespread reading of newspapers and journals kept the people more or less accurately informed concerning the trend of the times.

Men of heart knew instinctively that this development of a class of ill-conditioned working-people was wrong, men of brains knew that it was illogical and men of vision knew that it was unnecessary and could be corrected. These men (employers, employees and the public) working together patiently have been able to prove that it is better business and more profitable to see that the conditions under which workers live and work are as good for the development of personality and happy home life as the conditions surrounding the lives of the public for whom their products are made. After all, the deepest wish and greatest right of a man is a chance to develop to the greatest possible degree in mind, body and spirit. Any system which stands against this is bound ultimately to be cast aside.

The engineer occupies a stragetic position in industry because he is in direct contact with the workers. He it is that must understand the science involved in industrial operations, must see that scientific methods are used and must see that men are trained to carry out these methods. Consequently he is in direct contact with the workers and will be more and more so as industry advances. It is obvious then that he must be trained to have a sympathetic knowlege of the worker's psychology, needs and rights. How otherwise can he do his share in bringing peace into Industry, satisfaction to employer and employee and highest advancement to himself?

Engineering teachers have long recognized these things and have looked for a satisfactory solution of the problem before them. Therefore when Mr. Rindge of the Industrial Department of the International Committee of Young Men's Christain Association suggested to the Faculty of the Engineering College of the Ohio State University that a convention be called to get the subject discussed by men best fitted to speak on the subject, the Faculty was quick to act. A committee was appointed which with the sanction of the President of the University arranged the program. The program, as will be seen on reading this bulletin, was designed so that the subject of "Human Engineering" would be presented from all points of view including that of the employer, employee, engineer, teacher, wellfare worker, economist and business man.

The entire third and fourth year classes of the College of Engineering and the advanced classes in Economics were dismissed to attend the sessions of the "Congress".

D. J. Demorest
A. S. Watts
Committee on the "Congress of Human Engineering"

OPENING SESSION, THURSDAY MORNING, OCTOBER 26

DEAN CODDINGTON, PRESIDING

I wish to make a few remarks concerning this Congress, programs for which are in your hands.

Credit for the inception of this meeting is due largely to Mr. Fred Rindge, Jr., of the International Committee of the Y. M. C. A., who at a meeting of the Faculty of the Engineering College of this University suggested the good that might result from the holding of such a congress. Acting on his suggestion, the Engineering Faculty authorized the appointment of a committee to investigate the advisability of holding such a meeting, and upon a favorable report, the Faculty directed the committee to arrange for it.

I understand that Mr. Rindge has been of great assistance to the committee and also that he is to appear on the program. I take this opportunity of expressing our appreciation of his assistance and of the work of the committee. I also wish to express our thanks to the speakers who are to appear on the program who have given so much time and thought to aid in this cause.

The purpose of this Congress has been to bring together some of the noted men of the country who have made a study of the human factor in industry in contra-distinction to the material side; men who have been interested in improving the conditions under which their men work as well as increasing the output of their shops, and to have them give us the benefit of their experience. We expect to have with us in the audience representatives from many manufacturing concerns, from educational institutions and associations. I take pleasure in welcoming all these visitors. I believe that they and our Faculty and students will be benefited by the speeches and discussions which are to follow.

We are fortunate to have at the begining of our program a man who is actively engaged in educational work in a large manufacturing concern, a man who is to train those of our graduates who go into the employ of his company, and I take great pleasure in introducing to you Mr. C. R. Dooley of the Educational Department, of the Westinghouse Electric and Manufacturing Company, who will speak on "The Opportunities and Requirements of the Engineering Profession".

IDEALS AND REQUIREMENTS AND TRAINING FOR THE ENGINEERING PROFESSION

By C. R. Dooley

The first place on the program of this Congress and in a series of University talks is indeed an honor and a responsibility.

You students are looking for the biggest industrial opportunity you can handle. Employers are looking for men of best ability. Teachers are looking for best methods of training men to handle the biggest problems.

All three groups of men and women are interested in Ideals, Requirements, and Training necessary to successfully follow the Engineering Profession.

Engineering is a mode of thinking. Any man who considers all his problems without prejudice, who clearly discerns the facts from the opinions—the essentials from the non-essentials—and who searches continually for new truths and better methods, who is not controlled by superstition or precedent, who analyzes constructively or constructs, analytically, is an engineer. His field of work may be medicine, law, architecture, agriculture, mining, merchandising, machine design or chemical research.

Each of these fields requires its peculiar tools,—Mathematics, Physics, Drawing, History, materials, special information, etc.

It is clear, therefore, that the process of fitting one's self for a job requires two things:

1st—Mental training to develop right habits of thinking.

2nd—Special information to be used as tools. The former is by far the more important for with it the latter can be readily acquired.

The first point then, to that which I have to say this morning is: "*Have a plan*". Each one of us in this room this morning should have a general plan of life that he is following as closely as the earth follows its orbit around the sun.

In a haphazard way, our goods friends in years past have encouraged us to sobriety, industry, good manners, etc., and by and by something worth while would turn up. Today, by analyzing ourselves and

the jobs needing men, we arrive at a plan and go forth to turn up some particular thing.

And let me throw one side light on your plan; the object of a plan is not to arrive at any particular place but to develop and expand one's ability continuously. The vice president of a large corporation has as wide a field ahead of him to win by further self-training as the youngest Apprentice has ahead of him.

Next June, many of you will go forth to apply your plan to some innocent employer who, by the way, is not so innocent as he used to be for he too is developing a plan for employing only those men who are best adapted to his business. But you will find a job and get to work. Then you will find that business demands two apparently contradictory things:—

1st—Industry in each day's production.
2nd—Originality in devoloping new ideas.

The first is necessary to hold a job, the second to win a bigger job. Economy of production emphasizes the first so greatly that the second may be neglected to the sorrow of both the man and the firm. The first requires skill and high degree knowledge of the technique of the job. The second, analytical thinking and a well trained mind.

The first can be acquired best on the job under economic pressure. The second in formal training classes under the guidance of skilled teachers. Employers prefer young men of well trained minds, as I have defined the Engineer, because they can master one kind of technique after another as they are promoted over a long period of years.

The best kind of training comes through the working of practical problems scientifically. Such problems should deal only with fundamentals which have a very broad application. The study of very special subjects partakes too much of the teaching skill which requires mere memory to apply.

I noticed in one of the rooms this morning a professor showing designs of roofs and bridges to a party of students. I hope those fellows were not memorizing the different kinds of roofs but rather getting a clearer conception of the fundamentals of the construction of all truss structures. The exact forms of buildings are continually changing and when those students get to building roofs, some one is going to make a better one than those shown him now.

Consider the design of a bearing:— The fundamental principles involved are those of lubrication, friction, radiation and properties of metals. The exact design of the bearing is a piece of technique; an accomplishment learned in practice by applying these principles.

Take mechanical drawing—there are many men in the world who when they see a piece of bluepaper take off their hats to it. (Laughter.) To them the blue print is a sacred document.

A mechanical drawing shows plan views, not perspective. Top, bottom, end and side views may be made each on a different piece of paper and to a different scale. One view may be a blueprint, another a pencil sketch and a third a chalk sketch on the floor, yet the whole is a perfectly good mechanical drawing. Merely for convenience we have adopted certain standard conventions, such as all views to same scale, all views on same sheet, all views arranged on the sheet in their natural relation in the piece. Blueprinting is simply a method of cheap duplication.

First of all a draftsman must think intelligently in terms of mechanical pictures then, of course, he must master the technique to be understood by workmen who are to use his drawings. The other day I told a blacksmith to make me some special bolts. As I talked he drew a perfectly good mechanical drawing with a piece of chalk on the floor. The drawing was crude and not enduring but it told by a picture all I had explained in words and the blacksmith showed a very intelligent conception of what I wanted. In conducting a class in Literature you don't study the book to see how the words are spelled, spelling is mere technique. We read the book to get the ideas. Spelling, punctuation, etc. are merely the means to this end and not ends in themselves. It is no credit to a man to spell perfectly unless thereby he produces or interprets new ideas along some line of thought.

It is not in itself important to know that Columbus discovered America in 1492, but rather what were some contemporaneous events. —What of the perseverance of the man; the superstition of the people. The date is important only to give perspective to the setting of the story and must be considered along with all the rest of the information.

Six months ago I hired a stenographer. I interviewed twenty or more applicants. In the interviews I did not give a line of dictation nor require a line of typing. The first requirement was general intelligence, ability to comprehend the work of the office; ability to

catch the spirit and ideas of a letter as well as the dictated words. A stenographer trained only in technique will take notes, a hundred words per minute and put it all through the machine with or without punctuation, just as you dictate. She will get all your mistakes and little aside instructions in the body of your letter and when asked to do the letter over she'll say: "I wrote it just as you dictated it." (Laughter.)

The second requirement was a sense of refinement, genteel bearing, natural preference for order, harmony, and good form, pleasing appearance and manner, not retiring yet not over bearing. If a caller comes in when the manager is out, such a girl will not simply say: "Mr.———— is not in" and go on with her work but will get up from her desk with— "Mr. So and So is not in just now, perhaps I could do something for you" or if he waits she says: "Here are some new things we are doing—you might like to look them over while you wait."

The third requirement was merely that she had a speaking acquaintance with a note book and typewriter. Well! I hired just such a girl. The second day she was on the job I got after her for neater work and more of it. I knew she had the ability to improve her technique far beyond the others even those of greater experience, if given a little time and a little guidance, and so has she proved.

Take the musician—I take it, a person can never get music out of his soul by the training of only his fingers. Finger training is essential that the musician be able to execute properly, but to give the interpretation that appeals, the musician must be able to think musically and this means training the intellect. If this is impossible then better let the fingers go untrained.

So much for the plan for early training and now back to the broader idea of a plan of life.

The first thing essential in training ourselves is to make the proper selection. The selection of the right kind of work. The fellow who selects an engineering course simply because his brother took it or his father wants him to is making a serious mistake. There is only one reason why you should select an engineering course. Because you feel it in your bones. Because your desire along this line is greater than anything else. If you don't feel this way you had better try something else.

A desire will do for a basis of selection but not for final following. You must check your characteristics with other men in the same line and you must be reasonably sure you know what the real work of the worlds demands of a fellow in that line. In short "Here is a line I believe I like. What is the price of success in it? Am I able to pay the price? Am I willing to pay the price cheerfully?"

Let me tell you something of the modern plan followed by employers in selecting and training men. Last year we visited seventy-two schools, representing a total graduating class in Electrical Engineering of sixteen hundred men. We interviewed personally over seven-hundred. Of that seven-hundred, we selected two hundred and fifty-six, which we wrote down as desirable men. We believed these men best fitted for the type of engineering our Company had to offer. Four hundred and ten applied to us for jobs and we employed one hundred and fifty. This selection is made wholly upon personal interview and an examination of records both in and outside of prescribed class work from early childhood up to date.

Now if I am a student, I too must have a plan to get into industry. If industry has a plan and I haven't then I stand a long chance of getting a job, because some fellow wants a certain work done,—and not the job I really would love to follow all my life.

There are a number of ways being used to test the man as to his fitness for a given industry. Some examine the bumps on his head, and others subject him to hypothetical psychological tests These are good in a preliminary way but the final test is the simple analysis of the things he has done.

Let me give you a few stories of interviews with college seniors seeking employment, showing lack of energy and force of character. A young fellow of Cornell came into the office. After some common place introduction I asked him what he did last summer, "Went automobiling through Michigan. "How do you like driving"?—"I didn't drive, we had a chauffeur." "Have any tire trouble"?—Oh, yes." "What kind of tires do you use"?—Didn't know. "What was your gasoline mileage"?—"I don't know". "How are Michigan roads"? "Pretty good". "Oh, yes, but what are they made of"?—"I don't know." That fellow didn't know as much about an automobile as a five-year-old. Life to him was breathing and eating three good meals a day. When he left, I didn't have to tell him the answer, he could see it. He said, "Wish some one had told me this four years ago."

I told his professor, who replied, "Yes, I've tried too but he would not listen". But fellows, when your professor tries to tell you some of these things you don't believe it because you think that's what they are paid for.

Not long ago, I had some correspondence with a fellow named Hudson—a boy about seventeen living in Arkansas. One morning he walked into my office at Pittsburgh. Presently, I said "We didn't tell you to come on. Strikes me you took a long chance coming so far away from home with no job." He answered: "I figured I had always held good jobs in Arkansas and surely ought to find one in Pittsburgh." He was rubbing it into me but he didn't know it. (Laughter) Didn't intend it--just a regular, straight forward, wide awake boy. He said: "I met a fellow on the train last night. I told him I was coming up here, and he said: "If you don't get a job with them come over to the steel mills, I'll give you a job." That is real stuff, fellows. A boy 17 has an alternative job before he gets to the one he's after.

Here is another fellow I met at Purdue last winter. He had bucked the world as hard as Hudson is doing but he was older and somehow the load had left a little mark on him. At some time the burden had been a little too heavy for him, he had lost his nerve. He had no notion of giving up the struggle for an education, yet questioned the real wisdom of it. The first fellow I told you about had met no life burdens and his character was too shallow to have much force, while this one's character was too deep and reflective to have much speed. Somewhere between these extremes is the balance of the best load that every fellow must carry to develop himself most effectively.

Over in Pennsylvania, a good many of the students work their way through college by firing furnaces. One fellow had charge or four furnaces. He was always on the job and never lost a day in three and a half years. Yet he didn't know what kinds of coal he burned and how heat value varied among different kinds, never had made a recommendation for better coal. One furnace did not draw well but he took it as a part of the disposition of that type of furnace and never examined the flue which was found a year later to be defective. By way of contrast, another fellow worked in a boarding house. He knew where to buy the best potatoes, the best meat, and the particular way to please each boarder. He was a manager. You see the man who is doing things with his intellect as well as with his hands if

easily preferable and I leave that to your own judgment whether your original work is shoveling coal or working additional calculus problems. Use your head as well as your hands—think as well as figure. It isn't so much what you do as *how* you do it.

The industries have formed recently "The National Association of Corporation Schools." This means a still better plan to select and train men, and the time will soon come when the fellow who applies for a job with no conception of what he is going to get into will never get a big chance.

So much for the selection of men and now just a word about how industries plan for specific training.

Our training classes attempt to do the two things mentioned before:

1st—Train men to think straight in the conception and application of fundamentals.

2nd—Impart some information and specific technique to each man in his line. We would confine teaching to the latter if the former were not so badly needed.

We have classes in Mathematics and Drawing for boys out of public school learning the trades of Machinist, Pattern Maker or Electrician in our shops.

We have special training classes for Technical Graduates fitting them to be Salesmen, Designing Engineers, Manufacturing Managers, Operating Engineers, Construction Engineers, etc.

Then we have a night school which offers at small cost an opportunity for the shop man or trades boy to study fundamental science and thereby qualify for an engineering position according to his ability. The night school also includes English for foreigners and stenography, sewing and music for women. In all we have some fifteen hundred employes in training. Over a hundred men and women are giving at least some of their time to instruction and for the most part these instructors are chosen from among the men and women of the Company.

Little instruction is given in lecture form. Most of it is given either through problems or catechisms and in either case the correct answers require judgment and thought in selecting the data to state the problems or analysis of personal experience and general reading upon the apparatus under consideration as well as the proper technical solution.

Analysis is a pretty cold thing. Men who manage must add to it a measure of compromise and patience; you don't always get these in dealing with Mathematics. A manager in dealing with men must have flexibility. He must learn the laws of men as well as of material. Recently, I saw an article addressed "To the managers of men,—how to make them more content". I take exceptions to that word *Content*. The problem is *How* to develop men. I have attempted to give a birdseye view of the ideals to be followed and the general method of procedure by

1st —The Graduate Students

2nd—The Employer

3rd —The Teacher

Every man has only one life to live, he is entitled to the best life of which he is capable. Our whole plan must be on such a basis. Every man's job is a stepping stone to another job, limited only by his ambition and ability. There must be by-passes to all blind alley jobs. There is no inherent reason why daily work with its exacting technique and skill should not go hand in hand with mental training through a constant study of the fundamentals of science from the beginning to the end of life.

The human interest on the part of the manager of men is not merely sentimental though it is the fine sentiment that gives life to any business. Men must be encouraged to become the very best of which they are capable, if they are to form a thoroughly capable company.

There is no inherent conflict between systematic service to society and personal development to the limit of each man's capacity.

A man's work should be the largest part of his joy in life. It takes planning and it takes square humanity.

THURSDAY AFTERNOON SESSION

DEAN CODDINGTON PRESIDING

It will be a very great pleasure to introduce to you a man who is so interested in the problems involved in human engineering that he was willing to take time from the pressing duties falling upon a college president to come from the state of Delaware to address this congress. I am happy to present President Mitchell.

THE TIMELINESS OF THE CONGRESS OF HUMAN ENGINEERING.

By D. G. Mitchell.

Timeliness is the essence of statesmanship and I think timeliness is revealed in the idea that prompted this Congress.

Democracy and idealism find their abode in the American College. An illustration of this is found in the career of Charles McCarthy of Wisconsin, whose story has been admirably told by Sir Horace Plunkett in a recent number of a British Review. McCarthy was the son of poor Irish immigrants in New England. He drifted to Providence where he worked as a servant in a theater. One day he climbed the hill and knocked at the door of Brown University. How he got in no one knows, much less how he got out with a diploma. He ran a distinguished course in College. All especially remember what he did with the football in '97. He had as a fellow-student young John D. Rockefeller. When Sir Horace Plunkett attended a meeting of a committee dealing with the enrichment of rural life, he found these two men serving together upon it and still calling one another, Charlie and John. Perhaps only in College would you find such democracy.

The American college is not only democratic, but also shot through and through with idealism. I believe in the wisdom of youth as against the wisdom of old-age. Old men have the wisdom that grows out of experience. But young men by a subtle instinct are able to divine the forces that are to make the future. It is such prophetic vision in youth that has made possible this Congress dealing with the human factors in industry. The man who interprets best the genius

of the American people is not the lawyer, not the merchant, not the physician, not the scholar, but the engineer. I should take as the typical man of America, an engineer like Colonel Goethels. Our task was primarily an economic one, to clear and make habitable a continent. It is the engineer who attacks rough problems presented by nature, builds railways through forests, dredges harbors, bores mines, spans rivers, and humanizes the earth.

Another evidence of the timeliness of this conference is the fact that industry in this country is surging forward as never before. When I got on the train in Philadelphia last night, a man who sat beside me began a conversation, saying, "I am in a terrible fix; it is impossible for me to get goods to fill my orders. I have spent two weeks in the East pleading almost on my knees with the heads of concerns to fill my orders. They have been candid with me. They said that they were running their factories night and day and could only promise a future delivery". Along with this industrial prosperity we have greater restlessness on the part of labor and uneasiness on the part of capital than ever before in our history. Symptomatic of this crisis is the recent clash between the Brotherhood of Trainmen and the Railroads. The situation calls for leaedership of rare order, and instinctively the nation turns to its colleges and universities to find the men who will have initiative, love of fair-play, spirit of service, and constructive idealism that will enable them to solve these urgent problems.

Happily there is a change in spirit in industry that gives you a basis of hope in your purpose to put personality above production, to recover the man back of the machine. This tendency appears in many ways, but perhaps it has found no more pleasing expression than in the recent poem by Edwin Markham, which he wrote as a tribute to that true lover and servant of mankind, Thomas Mott Osborne, because of his unconquerable faith in his fellow-man, however fallen he may be:

"OUR BELIEVING THOMAS

For years the brute they saw,
Only the fang and claw,
    At Ossining.
The lash, the chain, the cell;
The dark, lone, silent hell—
Only the crime, the misery, the shame,
Were there before believing Thomas came
    To Ossining.

But now the man they seek,
Now to the spirit speak,
At Ossining.
The patience and the trust;
The inward voice "Thou must!"
The kindly word instead of iron blame—
These rule since our believing Thomas came
    To Ossining.

Yes, now the man they find,
And with affection bind,
    At Ossining.
And there a brother-band
Holds up both heart and hand;
And Justice too that is Love's working name
Dwells there since our believing Thomas came
    To Ossining.

No man has lost his chance
To conquer circumstance
    At Ossining.
"Fling the dead past away:
We stand upon to-day!"—
This was the faith that leaped to living flame
In that great hour believing Thomas came
    To Ossining.

Honor the dare and deed
That sow the golden seed,
    At Ossining.
Where each one has a friend
Unfailing to the end—
A father and friend that every man may claim
Since our beloved, believing Thomas came
    To Ossining."

Another sign of the times is the passage yesterday of the Federal Child Labor Bill. I remember a dinner at the Waldorf-Astoria in New York City about ten years ago given in honor of Mr. Robert C. Ogden, because of his untiring efforts in quickening the growth of the schools of the south. I happened to sit next to Mr. Richard Watson Gilder and I recall how Mr. Albert Shaw, the editor of the Review of Reviews, came over and stood behind us to say that Senator Beveridge, of Indiana, was thinking of introducing a Bill in Congress to put an end to child labor. I recall distinctly how dubious the step seemed. Ten years is a brief time in the history of any social reform. We have now a Federal Statute that insures a chance to every child, a chance to grow and to enjoy fresh air and play, a chance to enrich his stock of

human experiences through the school, and to build his life solidly for service to mankind. I rejoice that the poor children in the Cotton Mills in the South have in this way come into their own. They are as capable as the children of the more favored classes. The essence of democracy is, not a form of government, but faith in the capacity of the average man to grow and to achieve. The South has tapped in recent decades many new sources of wealth, but none of these can yield treasures comparable to the developed mind of its children.

The modern social program is finely set forth by Dr. Weyl in his book on "The New Democracy":

"The greatest revolution of the last half century is the revolution in the status of the child.

Similarly, in the interest of human conservation we must rectify or totally destroy our parasitic trades. There are two more or less distinct classes of parasitic industries; those which prey upon other industries, and those which prey upon human life. An industry is parasitic in this latter sense in proportion as it directly or indirectly increases sickness, produces deterioration, or shortens life.

It is in the sweated trades that the labor of women and children (especially of immigrant women and children) is most harshly exploited. In the making of artificial flowers, in the sorting of rags,in the fabrication of many articles of clothing, the work is carried on under the worst possible hygienic conditions for a derisory wage, in the interest of a cheap product.

From the point of view of society this cheapness is dearness and sheer wastefulness. It would be wiser to pay a few cents a gross more for our artificial flowers. It would be cheaper to pay our bounty in dollars than in the life and health of the workers."

Many are coming to recognize that it is a matter of economy and efficiency for a corporation to have a decent hall set aside for the workingman, so that he can eat his dinner under proper sanitary conditions. Too often now he sits down to eat his cold lunch amid the din and dirt of the very shed in which he had labored. The dinner hour yields no change and little refreshment. No wonder a blind impulse drives him to the saloon. A suitable dining-hall with coffee and such things furnished at a nominal cost, would mean to him health, vigor of spirit and zest in his work.

The import of such a suggestion is that we wish to appreciate the genuine worth and aspiration of these workingmen and treat them as brothers. I know a young man who worked during the heat of the

past summer in a steel mill. He found the nine and three-quarter hours there hard,and the accumulating fatigue could be seen in his face as the week advanced. But the man next to him was working overtime two days in the week until 9 o'clock, and remarked, "As soon as cooler weather comes I am going to work overtime four days in the week, as wife and I have bought a little home in the suburbs and we are striving in this way to pay for it." The founding of a home is the divinest act in human experience. To accomplish that end this man was willing to burn out his life. Such is the silent heroism that is found in the grimy shops of the land.

In a recent conference of social workers I heard John Mitchell say that the great anthracite coal strike a decade ago could have been settled in twenty minutes, if he and President Baer could have met and talked together over the situation. But this he said President Baer would not do. Hence they talked through the garbled reports of newspapers—John Mitchell in Stanton, President Baer in Philadelphia. The result was the whole country was made to suffer by reason of the continuance of the strike. I do not think that could happen in America today. Proof of this is the part that public opinion has taken in adjusting the difficulties between the railroads and the Brotherhood as to the eight-hour day. President Wilson delivered the decision of public opinion in favor of the eight-hour day. It remains for the workingman to make the right use of his increasing leisure, which should mean to him a sounder body, a mind informed by books from the public library, a sweeter home, intenser companionship with his children in quickening their nobler ideals, and surplus strength for civics and social service.

Big business has entered the educational field. Its advent is one of the commanding facts in the industry of our time. If I were asked what is the most significant advance being made in education, I should not point to the growth of high school, marvelous as that has been; I should not point to the increased endowment of our colleges and the growth of the great state universities; but I should point to the fact that 102 corporations are members of the National Association of Corporation Schools. Big business has found that existing educational agencies are not equal to the task of training her millions to carry forward the industrial processes of America. Hence corporations have felt the necessity of training their young men on company time in order to develop their powers aud to get the best results in the factory. Mr. F. C. Henderschott is the prophet of this educational purpose that is

working itself out in many a shop on the basis of mutual interest between employees and management. I cannot do better than quote a recent statement of his in regard to this new human factor in business management:

"In the organization of the early industrial corporations there were three general subdivisions of management: production, accounting and financing, and marketing. Later, as new markets were opened, there was demand for the traffic manager, but it is only within the last few years that recognition has been given to the workers.

Some of the more progressive industrial institutions have now added a fifth subdivision of management, which, for want of a better phrase, we may term "employe relations."

This division of management deals with the personnel of the institution or with the workers who are to handle the modern equipment of which all Amercians are so proud. There has come a recognition that equipment of high standard cannot produce industrial efficiency unless this equipment is handled by trained, skilled workers.

This fifth subdivision of management of industrial institutions is still in a promotional and embryonic state. There is, however, fairly general agreement among the best minds and authorities on the subject that "employe relations" must include:

First. A well-standardized employment department.

Second. A training department in which definite educational courses are given.

Third. A safety department.

Fourth. Retirement pensions.

Fifth. Profit sharing or systems for equitable distributions of earnings.

Sixth. Due regard for the workers' health.

Seventh. Savings and loan associations and the many other activities generally classed as "welfare."

American workers do not want philanthropy. They are earnestly seeking opportunity. This new conception has been retarded and in some instances defeated because it was believed to have been conceived from philanthropic basis "

I hope the spirit of this Conference will be to strengthen every agency that enriches the life of workingmen, such as the public library, the visiting nurses association, the Christian Association, the school, and the home. It is a mistake to conceive America in terms of

economics. America is a tremendous idea in process of realization, the idea of equality of opportunity for all, faith in the capacity of the average man to achieve, love of liberty, and the passion for peace. You are beckoned forward today by this glowing idealism which dwells in the heart of youth, which is the throb of the life of every college, and which is the secret of the sacrifices of our Fathers and their source of strength in building the nation.

DEAN CODDINGTON

This has been a very stirring address and I am sure that we all have a clearer vision of the destiny of our great industrial democracy and the opportunity of such a meeting as this to accomplish good.

Our next speaker comes to us directly from a great industry where he must direct large numbers of men and it gives me pleasure to introduce to you Mr. C. R. Hook, Vice-President of the American Rolling Mills Company.

HUMAN ENGINEERING IN STEEL MILLS

By C. R. Hook.

I am sure you are not looking for an eloquent address from one who is only a steel works superintendent. I shall endeavor, though, to interpret the subject as I see it as a superintendent, and as my experience has brought forth the facts.

This is a Congress of Human Engineering, and Prof. Demorest has said "The purpose of this conference is to put more definitely into engineering education the idea that it is necessary for the engineer to understand the human factor with which he will have to deal, as an engineer, as well as to understand the ordinary materials of engineering. We want our men to leave here with a knowledge of the workers' psychology and his needs and possibilities, etc., so that he can get along with them without friction and do his best for his employer as well as for the workers.

Psychology is the science of the Human Soul and its operations. We are therefore particulary interested in all those things which affect the man's mind. The generating station for all human thought and effort is in the head, and a man's value is measured as much by his capacity to receive as it is by his ability to give.

The technically trained man can not hope to have the non-technically trained man accept his views and ideas unless he in turn has the ability to diplomatically cultivate, and the capacity to receive the ripened fruits from the worker's tree of experience.

Engineers may conceive and build the most wonderful and complete buildings and machinery but they are inanimate and absolutely worthless without the proper men to use and operate them.

It is indeed encouraging and it means much to our industrial growth and improvement, to have a great college like the Ohio State University actively engaged in promulgating the study and spreading the truth as it relates to the connection between success in industry and The Human Element.

Permit me to picture the course and methods of the really successful industrial leader of today.

The truth I want to leave this afternoon with the students of this university, is that if you are to be such men, you must be possessed of high ideals, of sound moral principles, a sound body and an absolutely democratic demeanor.

I have seen with my own eyes and I have heard of a number of college men who, while going to college or upon their return home, have taken great pride in telling the young ladies and others upon whom they wished to make an impression of "the hell of a time they had carousing, etc." Now I want to say to you right here and now, that if that is the spirit with which you tackle your job, (excuse the profanity) "you will wait a hell of a long time" for promotion when you get into industry.

Dr. Charles L. Dana in a recent letter to the Editor of The New York Times on the subject of "A Biological Work Day" has this to say:

> "The amount of work one can do depends on its kind, its continuity, on the mental and physical makeup of the worker, *and also on how and where he spends his other hours.* Eight hours a day is rather more than is assigned in the processes of early education; it is a good deal less than is usually given by employers, men in business, in farming, in professional life, who can control their activities and are in a measure masters of their hours. Eight hours is much too long for certain kinds of strenuous physical work and much too short for many kinds of mental and physical labor that possess interest and variety. We must sleep about eight hours, but we may work four or twelve hours daily.
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> "As it is not a definite thing, this ideal period of work, or time of being industrially and fruitfully employed, and it being admitted that a definite working day has no physiological basis, I want to urge upon economists the search for and adoption of a biological day. By such a day I mean one in which consideration is paid to the way the whole twenty-four hours are spent, to the whole living interests of the man. It is just as important to provide for one part of the twenty-four hours as the other. But heretofore attention has been centered on the so-called work part. The term work also is much used as if work were a crime or a painful or unpleasant thing—to be cut out as much as possible. But this is not true. The happiest part of life is in employment, as every one would admit if we used the word occupation instead of "labor or work."

I would call your attention particularly to the first sentence and to "By such a day I mean one in which consideration is paid to the way the whole twenty-four hours are spent, to the whole living interests of the man."

My purpose in quoting from Dr. Dana's letter is to emphasize the strength of my contention that the efficiency of the man in the plant is determined very largely by his actions and his environment with-

out the gates. It is almost useless to try to appeal to the reasoning powers of a man whose brain is sluggish and almost inactive as a result of indulgence in alcohol. In the same way is it almost impossible to talk about order and cleanliness in the shop when there is no order or cleanliness in the home or the community.

The first thought of that man who expects to get the greatest efficiency out of an organization must be for those things on the outside which make for a sound body and mind. He should show by his own personal interest that he is in sympathy with the church, with all movements for the betterment of the schools, the homes, the local goverment, the parks, the community, sanitary conditions, and in fact anything and everything that is an influence for the improvement of body and soul.

To properly handle men inside the plant it is necessary to get their viewpoint and this is best obtained by contact with them on the outside; in the church, in the Plant Club, and other agencies which permit of the free social intercourse of all the various types of men.

Social Service Work is a large part of the general subject of Human Engineering. Not long ago I read an article entitled "Creating Leaders." I think it was written by Mr. Gannt and it appeared in The Engineering Magazine. I clipped part of it because it covers the subject of Social Service Work so well and so accurately, and I want to read it to you because it states the fact better than I could give it to you in my own words:

> "The title 'Social Service Work' is a good one. All of the engineer's work is service work, in that he makes his living by serving somebody, and much is social service work, for in much of what he does he serves the community. This is not exactly the meaning of the title, but it gives an opportunity to emphasize the fact that in an organized community we all earn our living by giving service. When one man hires another it is his service he wants. When a man buys a machine, it is the service of that machine he wants—not the specific machine—any other machine which could perform the same service equally well and equally economically would do.
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> Engineering schools have successfully taught the laws of material and forces and the methods of adapting these materials and forces to the use of man; but they have almost entirely disregarded the human element, a knowledge of which is absolutely essential for the proper utilization of any mechanism which the engineer may contrive. If we would direct successfully the operation of any mechanism, we must have as complete a knowledge of the men who are going to operate it as we have of the mechan-

ism itself, and the Social Service Work is, to my mind, the best available method of supplementing the knowledge obtained in the class room.

Without an intimate knowledge of the workman, a college graduate is to apt to assume that the workman, because he has not the same kind of knowledge the college man has, is necessarily ignorant and a fit subject for contempt. The workman has indeed a great deal of knowledge, much of which is far more practical and better suited to his needs than that the college man can give him. Moreover, the workman readily recognizes that the college man knows but little about those subjects with which he is most familiar, and the contempt which the college man is apt to get for the workman before he knows him is only a small fraction of the contempt which the workman frequently gets for the college man.

"The Social Service Work which has attracted the interest of so many men is certainly the best way which has yet been devised to enable the college man and the workman to learn and to appreciate the good qualities of each other. The college man is to apt to feel that by reading a few books on industrialism or political economy he has acquired a broad knowledge of working conditions, but he very soon finds that many of the general principles so widely exploited in such books produce, in special cases, results which are not even hinted at in the books."

All Social Service Work is and should be clearly understood a Mutual Work!

Unless a man is conscious of the fact that when he serves the community or an indivdual he is serving and helping himself, he will perform his act in a patronizing spirit and the result will be negative instead of positive.

Several days ago a committee came to see me to secure my support for a certain scheme which was to be worked up, so they stated, "for Charity." I immediately gave them to understand that there was a big difference between people who were charitably inclined and those who did things "for Charity." People who are willing and want to help themselves resen the idea of Charity, as it is commonly understood, and charitably inclined people refrain from the use of the word.

Every time you dosomething to better the condition of your fellow townsmen you are making it an easier aud better place for you yourself to live in. If I do anything in the town in which I live to make housing and general health conditions better, I am making it just that much easier to bring my boy up properly because of environment in which his school associates live.

I mention all these things because it is the knowledge of the operations of the human soul that makes it possible for the industrial

leader to know how to appeal to the reasoning powers of the men upon whom he must necessarily depend for his own individual success; because it permits him to understand and to impress the men with the fact, that, they are working *with* him and not *for* him.

When a man determines to apply for a position in any of our large industrial plants today, the first place of contact with the organization is at the Employment Bureau and it is extremely important that he be treated courteously and that everything possible be done to give him a good impression of the plant whether he is employed or not. The plant spirit of loyalty and co-operation is greatly influenced by the opinion and attitude of those without. If a man's first impression is good he enters the works with the proper attitude of mind and it is much easier for his department head to secure his co-operation and his support of the company policies. When a man is handled gruffly or impertinently at the gate he generally makes a mental reservation to the effect that he will "get even" later, and as a result the Company suffers because of the incompetence and lack of vision on the part of its first representative. In all my experience I never ran across a man, no matter how rough he was himself, who failed to appreciate dignified courtesy.

A few years ago the Employment Bureau,as it is organized today in any well run industrial establishment, was unheard of, unthought of, and would have been considered an extravagance. True there were employment agents whose job it was to find and hire men when they were needed, but no attempt was made at scientific selections and men, after they were "hired" were "fired" with just as little thought being given to the effect it might have on the future of the individual and and the general efficiency and morale of the plant.

Gradually, the scientific study of our plant efficiencies and losses, disclosed to our "cost sheet surgeons" and efficiency engineers the fact that the greatest losses were due to wasted human effort and the lack of effort, resulting from the improper placing of a very large proportion of our workers.

Today the employment of an organization consists of the practical application of scientific methods of selection. I should add, provided there are any men from which to select.

Every possible effort is made to place men where their work environment will be in harmony with their particular characteristics. To this end the up-to-date Director of Employment familiarizes himself with the character studies which have been made by Dr.Blackford,

Dr. Merton and others, and with the psychological research work done by Dr. Walter Dill Scott, Professor Muensterburg, etc.

Mr. Market of The Emerson Company, efficiency engineers, who has been with us for the past three months assisting us in our employment department, has been giving us a series of talks on character analysis. He states that he has found from a review of the work of Dr. Blackford and others, that there are nine fundamental variable laws underlying the study; Law of Color, Form, Size, Structure, Texture, Consistency, Proportion of Body, Face and Head, Expression and Experience or Condition.

Law of Color being indicative of the inherent force in the individual. For instance, Dr. Blackford states that the normal Blond has "positive, dynamic, driving, aggressive, domineering, impatient, active, quick, hopeful, speculative, changeable, and variety loving characteristics," while the normal Brunette has "negative, static, conservative, initative, submissive, cautious, painstaking, patient, plodding, slow, deliberate, serious, thoughtful, specializing characteristics."

Form refers to the contour of the face or any of its features as seen in profile, and gives an indication of how the individual expresses his inherent force in action.

Size influences the movements of men. From ordinary observation you will notice that large men, whether tall, bony and muscular, or corpulent, move with more deliberation, more calmness and are slower than small men.

Structure refers to temperament and is influenced by

Brain and nervous system, or Mental temperament.

Bony and muscular system, or Motive or mechanical temperament.

Digestive and nutritive system, or Vital temperament.

Thus each law in its turn has reference to the indication of some particular characteristics and, therefore, in making a practical application of the analysis, great care must be exercised and the characters istics of any one law must always be considered in conjunction with the characteristics as shown by the other variables.

Great progress has been made and many valuable facts have been unearthed in the study of character analysis, but personally I believe the general facts should only be used as an *indication* when making a practical application of the study to determine the particular characteristics of the individual being selected.

As soon as the visual analysis has been made and the indicated characteristics determined, carefully worded questions and psychological tests should be applied to determine whether the characteristics indicated are dominant or have been conquered.

I mention these things to show you what a careful study is being made to discover the particular characteristics and aptitudes of a man when he is being selected for a place in the factory today.

It should impress you with the fact that there is a very close relationship between individual aptitude and departmental efficiency and success.

As further evidence indicating the thought that is being given o the scientific selection and placement of employees, permit me to quote from an article entitled "Building up an Organization" by Mr. Richard A. Feiss, General Manager Clothcraft Shops, Cleveland, Ohio, which appeared in the July issue of the Dodge idea:

> "A great deal has been said and written about psychological tests for the purpose of selecting employees but the little that has been done of practical value has been limited entirely to a few tests for special aptitudes where special aptitudes are required. For the present at least such tests, even when practically developed, can be used only for the determination of individual limitations. At the Clothcraft Shops, investigation and experiments have been carried on for this purpose. The tests that are being developed consist of general intelligence tests, including a test for ability to follow instructions, and a series of tests for dexterity. Professor Walter Dill Scott has been retained for the purpose of assisting in the development of these tests. Recently a series of tests were given under his direction. Twenty-one subjects were chosen for the purpose and included members of the organization holding executive positions and operatives of different degress of efficiency in various kinds of work. In practically every case the results of the tests checked up accurately with the estimate of general intelligence and dexterity based on records and personal acquaintance over a long period of time.
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> "The object of these tests is two fold. In the first place with the best of care, errors are bound to occur in original selection and placement. People are not all suited and some are occasionally selected who are mentally unfit for the industry.
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> "This under no circumstances means that all the mentally deficients are unfit. There are of course all kinds of mental deficients, and there are a great many different kinds of work in most industrial establishments that can be done as efficiently by the subnormal, mentally, as by the normal. The human makeup is so complex that many instances have been found where a normal individual was incapable of reaching the same efficiency in certain kinds of work as a sub-normal had reached.

"It is the aim of these tests to aid in the selection of people, to avoid placing people who are either normal or sub-normal on kinds of work for which they are very likely to prove unfit."

It is certainly unfair to employ a man and then give no thought whatever as to whether or not he is fitted for a bigger position than that for which he has applied. The employment bureau should know what kind of men are needed for the various classes of work throughout the plant.

In the steel plant we have various kinds of work. In almost every one of the divisions there is a different type of man required. It is not fair to the man to place him where he is not going to have the best opportunity to develop his latent powers.

After the man has been employed, the employment bureau should make every effort to acquaint the employee's foreman or superintendent with the indicated characteristics of the man in order that he may be handled and guided accordingly. Every superintendent or foreman should endeavor to check up the characteristics and aptitudes of his men, whether they have been indicated to him by the employment department or not, for a true knowledge of the temperament of his men will permit him to use such methods in handling them as will secure their co-operation and the most intelligent prosecution of their particular jobs. The cultivation of the spirit of loyalty and the desire to give their best brain and physical effort to their job on the part of the men, is of far more value to the company than the ability of the foreman to perform each job in his department with the highest degree of skill and efficiency.

Great care and intelligence must be used in handling men in order that they may have the opportunity to do the best for themselves and for their company. Some men think slowly and must be talked to slowly in order that they may have time to absorb the thought you are trying to give them. On the other hand there are men who perceive very quickly and it is useless to waste time going into too much detail or explanation with them as it would have a tendency to irratate them and make them lose interest.

Control of your own temper is absolutely essential if you would get the best effort and work from the man who is subject to brain storms. You may lose a very valuable man to the company and yourself and a very great personal friend through your lack of tact or your inability to prevent men of this type from exploding, there is no truer saying than "whom the Gods would destroy they first make mad."

Too frequently a mannerism is mistaken for an unpleasant characteristic. It is not so much *what* you say as *how* you say it. I would urge you to make the most determined effort to acquire the habit of patient and dignified friendliness and encouragement.

There are three or four experiences which come to my mind today and which I would like to describe in order to illustrate the value of patience, encouragement and courtesy.

Several years ago there came into a large steel works, a man about thirty-five years of age, who had graduated from one of our formost engineering schools as an "honor man;" had succeeded admirably as a mechanical and sales engineer, was extremly likeable, and had been chosen as the chief mechanical engineer in charge of the entire mechanical maintenance of this plant because of his exceptional mechanical and mathematical ability. Prior to taking hold of this last mentioned position he had had no experience in handling large numbers of men, and at the end of about eighteen months it was found that it was useless to attempt to retain him in this particular position because of his inability to co-operate with the department superintendents and his lack of tact and consequent failure to co-ordinate the efforts of his foremen and their men.

He did not possess calm judgment, and it was absolutely impossible for him to repress his own opinions temporarily while extracting the advice or opinion of one of his subordinates, his fellow superintendents, or even of his superiors.

He was one of those men who, by his manner of receiving or approaching an employee, put the man on the defensive immediately instead of making him feel at ease, and thereby secure his confidence and co-operation. If a workman came to him with a suggestion, he had the unfortunate faculty of giving the man the impression of hostility to his idea before the poor fellow had a chance to say a half dozen words. He generally started out by saying "Well what do *you* want?" instead of "Good morning, what can I do for you today?"

The most impractical suggestion deserves the most courteous consideration and very great tact, and care should be exercised in turning down a suggestion, in order not to discourage the man and kill his loyalty and iniative ability. No suggestion should be turned down immediately, and every effort should be made to impress the man with the idea that an adverse conclusion had been reached only after very careful consideration on the part of the man in charge.

Permit me to tell you now of an experience I had not very long ago with one of our own superintendents, and a very great personal

friend of mine. This particular man is one of those wiry, energetic, volcanic, high tempered fellows, who, if permitted to follow his own immediate inclinations, is at times his own worst enemy, but he has a great heart and is fundamentally sound.

He called me on the 'phone and said he must see me at once on a matter of decided importance. From the way he talked over the 'phone I knew he was as mad as a hornet, so I told him to come right over to my office and I would see him at once. As soon as he hung up the receiver I began to plan my own attack on Bill when he got to the office so that I could get his feet down on the earth before we started to discuss what was on his mind. He arrived in a few minutes and the moment he came through the door I discovered that my diagnosis of a brain storm was correct, so before he had a chance to say a word to me I said to him "By the way, Bill, before you start to tell me what you called me up about, I want to get your advice about a little matter before I forget it;" so Bill and I chatted over *my* proposition until I thought he had composed himself sufficently to talk over what was on his mind dispassionately. To make a long story short, Bill left my office in a good humor, we arrived at a mutually satisfactory understanding as to how best to handle the situation over which Bill was so disturbed. Bill was saved from the possibility of taking a stand from which it would have been hard for him to retreat with dignity and "they lived happily ever after," to put it in story book fashion.

I could continue and give you example after example of men who have been saved unto themselves and made extremely valuable men to their company through the exercise of patience, courtesy and encouragement on the part of their superiors in position.

George Horace Lorimer once said—"Give most women enough note paper and most men a good listener and they will tell all they know." Cultivate the knack and habit of being a good listener.

In conclusion I want to say a word about school and team spirit and its relation to industrial leadership and success.

When I went to school, and I suppose it is the same today, we had fellows who were always knocking the school and the teachers, always predicting defeat for the athletic teams and in general were just everyday pessimists and joy killers. Then on the other hand we had those fellows who always had a good word for the school and its organizations, were out yelling themselves hoarse for the team, even though they had been turned down for a place in the line-up, were always encouraging the captain and his men regardless of whether the team won or lost. I trace those men into industry and

I find the men of the first class still the pessimists, still trailing along in the rear and making up that part of the organization known as the knockers and I find they are the fellows who are always kicking about the company policies, always predicting that the foreman or the superintendent is going to lose his job, always making excuses for their own shortcomings and attributing their own failure to advance to the "pull", this, that or the other fellow has with "the boss". They spend so much time framing up excuses for themselves and figuring out the other fellow's deficiencies that they have no time to improve their own faults and as a result, Opportunity passes by without giving them a chance to even tip their hat.

On the other hand I see the men of the second class filling the positions of responsibility and trust and leading the organization on to victory through the development of the spirit of team work, which is the other name for co-operation.

The man that gets the idea that everybody else under him is working *for* him has the wrong idea. If he wants to be able to accomplish very much he must work *with* his men and *they with him*.

There are many things that affect the attitude of the men in industrial life. All those things must be studied; they must be the consideration of the man who would be successful as an industrial leader. It is not one thing, it is the combination of all things that influence the happiness of a man in his work, that must be studied and applied in order to develop the most loyal and efficient organization.

THURSDAY EVENING SESSION

DEAN CODDINGTON PRESIDING

Our program is proceeding nicely. We have had three strong addresses already today. We have heard the ideas of a man engaged in educational work in a great manufacturing concern, those of an operating superintendent in a steel mill and those of a college president. This evening we are going to change the order from that of the printed program because Professor Newell is unable to appear at this time and we are to listen to another type of man who is an employer actively engaged in the industrial world. He is also a retired naval officer. I take pleasure in introducing to you Captain W. P. White, General Manager of the Lowell Paper Tube Corporation, who will talk on "The Hours of Labor—or Getting on in the World." He comes representing the National Manufacturing Association.

THE HOURS OF LABOR OR GETTING ON IN THE WORLD

By CAPTAIN W. P. WHITE

I suppose all of you, when reading a book, judge of that book somewhat by the preface. I think that a speaker comes before an audience much in the guise of a book. I am going to give you a preface by way of informing you why I hold the opinions I have and why I have the liberty to come here to express them.

I was born in Illinois in 1859 and may be reckoned among the elders. I was born in a small town. I went to school in a small town. I lived sometime on a farm and went to school in the country. I had the happy fortune of spending some of the best years of my life on a farm. I went finally to a state normal school. There I was taught with young men and women who aspired to be teachers, so I had an unusual schooling for a boy. At fifteen I entered the U. S. Naval Academy, graduating in four years.

As a boy, I had known something about work and something about working with men. I had known something about the circumstances that surround those who from day to day, live by what that day's labor may produce. For thirty-two years of active service as a naval officer, I was primarily interested in the enlistment and train-

ing of men. Only once was I detailed for other duty, that of inspecting material being installed in naval vessels under construction. All my other shore duty was in connection with the enlisting of men. Like other employers, we had to go into the labor market for men. These men were therefore as truly mercenaries as any troops that fought against us in the war for American independence. The same is true of our army, a most deplorable condition for a country such as ours, and until this method be changed, we can never be safe in national life, or be sure of national progress.

Six years ago, I went on the retired list of the Navy. Having still some active years of life, I went into a manufacturing establishment as Treasurer and General Manager. For five years, I have lived the active life as a manager and employer of labor. I am a member of the Board of Directors of the National Asssociation of Manufactures, and Chairman of the Industrial Betterment Committee. I am here tonight to speak on "Hours of Labor or Getting On in the World".

The subject "Hours of Labor" has long been a topic for general discussion. A solution of the question is not so simple as some may think. A very distinguished gentleman has said that society has approved of the eight hour day. If any of you young men expect to make a success in life and limit your endeavors to eight hours per day I should advise you to go to some warmer climate than the United States. Other wise, the cold will be very severely felt. (Laughter). Success in life means work and hours of labor are only hours of opportunity. Those who wish to limit the hours of opportunity do so not because they wish individual success but hope thereby to distribute the success through the whole mass of labor by keeping it on the dead level of opportunity.

This Fall, in taking up the question of hours of labor, our committee has received answers from some 1264 members of the National Association of Manufactors, involving 907,000 employees. Of these 731,700 are males, 141,700 females, 18,600 are boys and 14,900 are girls. The boys and girls are between the ages of fourteen and eighteen years.

We hear a great deal concerning the kind of labor in industry, particularly the large proportion of boys and girls and the number of women employed. But why is it that *any* of these are employed in industry? Your attention is invited to the large number of women and children employed. Let us take a look backward. Originally, men were hunters and herdsmen. The women took care of the building of the home and all that pertained thereto, and the cultivation of plots of ground about the homes. As the population increased, the men became

more civilized. They ceased to be hunters and became tillers of the soil. The women's work was restricted to the household. The family wants were mainly supplied by the family itself. In my early days in the West, I remember that some of this independence still existed. In our modern day, machinery has done away with the necessity for much of this work. Modern industry can do for society more easily and much more cheaply than individuals can do for themselves. Housewives no longer make the family clothing. The family is clad in garments of the latest style from the shops more easily than they can be produced at home.

With the introduction of machinery, however, wages have not kept pace with the family requirements. If the father's wages are insufficient, the rest of the family go into industry. Sometimes these wages are used entirely for the individual wants, but in large families it has become necessary for the boys and girls to help their parents by paying at least part of their own support. Must these children go into industry without any adequate preparation? For this our schooling is greatly responsible.

The schooling that I received in the country was identical with that I received in the town. Teachers were educated in the same normal school, and were taught in the same manner, whether in the town or country. Naturally, for further educational opportunities, children were sent to town. If the boy could not go to college, at least the girl was sent. The boy did not have the opportunity, or not unfrequently did not have the desire for the schooling that the girl did have, so that the girl in many instances was better schooled than the boy, but not necessarily better educated. Education is something that may be had by taking advantage of opportunities wherever we may be. The men at the head of American industry today, men of the greatest wealth in our country are few of them college bred men. They have come up out of the ranks by taking advantage of daily opportunities to advance themselves. They may be diffident in general topics of conversation, but approached on subjects pertaining to industry, you will find them vastly informed and able to discuss production in minute details. It is this opportunity for advancement that has been given to Americans as a heritage. This advancement has been possible because the individual has been disposed to labor. The doors of the workshops should be wide open to people who desire to work. It devolves upon the individual to seize the opportunity and make the most of it.

But in densely populated parts of the world, one will not always find the opportunity for labor open. People have gone to town faster than the town offers opportunity for work. In our country, a great mass of workmen have come from the otherside, trained by other conditions. These have brought with them the ideas of organizing, restricting the benefit of employment to those in the organization. It is right — undeniably right — a right that must be preserved — thus to organize to sell their labor if they so desire, but it is equally essential to our welfare and the preservation of our liberties that we insist that the individual laborer may also sell his labor without any regard to restrictions as to when, where, or with whom he shall work. In order, however, to take care of the additional workmen, the labor unions are continually asking for reduction of hours of labor. With the reduction of hours of labor, they do not expect a reduced wage proportionate with this reduction but insist that a reduction in hours must carry no reduction in wages; nor do they promise any effort to increase the output commensurate with the reduction in hours of labor. The workmen carries into his reduced hours the same habits of labor he had before, so that increased numbers must be employed to make up for reduced production. This means an increase of the plant, increase in the cost of labor to produce a given amount, increased cost of the product which all goes to increase the cost of living. To offset these increased costs of production, machinery is devised and new methods used so as to reduce the labor cost. With the increasing use of machinery, the skilled mechanic has now become merely a machine tender. No longer are three or four years required to make a good mechanic. A rating of machinist may now mean a machine tender.

I do not stand here as an advocate of long hours of labor. I do not say that a reduction is unnecessary, but I do say that as a result of a reduction in hours, there must be increased efficiency. Mere reduction in hours may be a disadvantage to the laborer himself. In order to advance, the laborer must have opportunity to sell all the hours of labor he can perform each day without impairing his efficiency as a laborer. What those hours may be, we are not yet able to determine. They vary in different occupations and in different circumstances in the same occupation. We may find that eight hours is too much and in a certain industry even six hours may be sufficient on account of the excessive exhaustion due to conditions of labor.

But we must also distinguish between labor and employment. When does labor begin? Take the plumber, for instance. He leaves

the shop at eight o'clock to go out on a job, and travels to and from his work. All go in as hours of labor, all go in on your bill. Is he doing his share for society when he has finished eight hours of such employment, forty-four hours per week? I do not think so, but he is enabled to do this because he belongs to a labor union that is able to maintain a closed shop, and so maintain a monopoly in his particular kind of business. Society pays the bills just as it would for any other kind of monopoly. This we do not believe to be the solution of the question, for in that great home of the labor union, Australia, high rate of wages and the closed shop have led to neither industrial peace nor industrial progress. Australia has not solved the industrial question, however it may have equalized the laborers' wages.

With the large number of people driven into industry—into the factories to work—which is resulting in restriction of hours of labor, in order to accommodate the increasing number it is necessary for the laborers so engaged to continue to enjoy the high wages, they must be protected by tariff. The industries of the United States have been built up by such a protective tariff. The farmer, however, who purchases the product of this labor has to sell his surplus product in the markets of the world and would be able to buy in this same market but for the protective tariff. The first vote that I cast was for a Republican Presidential candidate who was elected on a platform of tariff reform. I might say that the same thing has been advocated ever since. Wherever there has been a revision of the tariff, there has been a readjustment, too.

Living, in America, in comparison with the wages received here, is cheaper than anywhere else in the world. The laborer in manufacturing industries is the most favored person in the community. Many have come from abroad and here found the opportunity to labor. They have come here ignorant of our language, ignorant of our institutions, and he who improves his condition has risen from the ranks, due to this opportunity. This opportunity which America offers is for young men to go out and be leaders in industry, and the only way that this may be done is insistence on our part of the vital principle laid down, that an individual laborer may sell his labor as he pleases at the price which he is willing to accept, with no interference with his employment.

How may one know whether he is being adequately paid? A practical way is to appeal to the employer or boss for a raise. If he does not give to you, go out and search elsewhere for employment, but if you are worth more to him, rather than take on another employee and

educate him to your work, your wage will be advanced. I once asked the question of a street railway conductor "How do you know whether you are being paid enough?" and he replied that he did not know. I said to him that when he found another man in the same circumstances as himself willing to take his job at the price he was getting, then he was getting the market value for his employment. He thought the matter over a moment and then said that he guessed that was right. This also may be considered a principle of living.

Men say "Through our efforts industry has been able to build up great factories, develop machines and make enormous fortunes. It is our right to demand our share in this increase". I say "No". The up-building of factories is the result of some one's saving, someone's efficiency, someone's foresight. The workmen's share comes in the opportunity for work. Buildings and machinery are of little value without the workmen. In order that the mill may run and run successfully it requires skillful management and forethought. We have no way of determining what the profits in industry should be.

Mr. Ford is known as an advocate of the eight hour day,but Mr. Ford has a very highly specialized industry, the product of which is in great demand. He has put into the market the cheapest automobile that has yet been built. From this he has made enormous profits. By skillfull management and investment he has been able to build up a great industry. By the stimulus of high wages, he has been able to attract to his factory the most skillful mechanics, and those most able physically to carry on his kind of industry.

What does the eight hour tour in industry mean? Does it mean forty eight hours of work a week in the factory as well as for the laborer? Does it mean hours from eight to twelve and one to five in which the workman may come into the shop, ring in his time, proceed leisurely to take up his work and discontinue it in time to leave the shop at the end of his tour of duty? Does it mean eight hours of intensive labor in a factory running twenty four hours a day, when the laborer steps into his place at the beginning of his tour of duty and stays at it the full eight hours, as in Mr. Ford's factory? Which of two factories using these methods will succeed?

If we are to have an eight hour day applied to the factory as well as to the men, to apply to all employment as well as to manufacturing, will it not take away from the fields and farms the men who labor therein and bring to the city men seeking employment? Will not these heartier men, in competition with the weaker townspeople, force the weaker members of society to the wall and bring about pri-

vation and suffering to the weaker members? This certainly seems to have been the experience in England, where efforts are now being made to ameliorate the condition of the great numbers dependent upon charity by the introduction of insurance for sickness, unemployment, etc. Where do they get the money? By increased income taxes, by increased inheritance taxes that are wiping out the savings of generations.

DISCUSSION, following the address of Captain White.

PROFESSOR CODDINGTON

Ladies and Gentlemen you have certainly heard something this evening that ought to start you to thinking. You may have heard something not in accordance with your views at this time. It is therefor proper at this time if Captain White has said something you don't quite understand to ask and see if his views are correct or yours are correct. We will be glad to hear some discussion on this subject.

PROFESSOR DEMOREST

There are two or three fundamentals we can all agree on. One is the common necessity and privilege of doing useful work. Man must work.

Second, that useful work is for only one purpose; that is for the development of the home; to make life more worth the living.

Now the point is, what amount of labor will produce the maximum of human happiness.

Further, if six hours will produce all the real needs of humanity, is there a reason for working more. The point is, Industry exists not for Industry's sake, but for the purpose of happiness and good of the community. That must be the basis of all industry.—Happiness and good of the community.

CAPTAIN WHITE

How are we going to determine the amount of work that a man shall do, particularly to fill the needs of the home?

I lived in Samoa for one year. Because of the plentifulness of food there,—the bread fruit, and the cocoanut are an ever present source of food,—perhaps three hours of work are enough to make the Samoan happy. Conditions are different in every country, the human needs are different; but is the man contented to live from day to day, trusting to fortune to take care of him in his old age. I think not; we are not contented, we want to get on, and the only way is to be willing to work longer hours than the other fellow and to save

against the rainy day. For one living in an industrial community where there is competition of labor, the only way to get ahead is by saving. It is the duty of each individual to take care of the future: if he does't take care of himself, if he squanders his daily wage, if he abuses the present opportunity, when hard times and sickness comes on, and the inevitable old age arrives he comes back and is a pensioner on Society. Society owes no such pensions. True there are corporations which grant pensions, sick benefits, etc., but this is done as part of a reward for faithful service.

Society should have something to say as to the working hours of the individual. There should be a limit of the working hours in order that society may not be burdened later on by injury resulting from excessive hours of labor.

MISS MACCORBLE

I would like to ask who is to decide the length of hours in a day that would impair a workman's usefulness, is the individual to decide that, especially in the case of young girl workers?

CAPTAIN WHITE

That is difficult to answer. That is something about which we are to study. One girl may break down and another may be able to carry on the same work. Same way in school, one girl be able to keep up and another breaks under the strain. So the work of girls in industry is to be carefully watched. I don't know that we should limit by law for the purpose of protecting girls from injury. The law does not always work out that way. In the District of Columbia the hours of shop girls are limited by law. As a result the employers of girls in order to keep within the law, do not permit the girls to return to the shop during the middle of the day. The question is—what are the girls going to do during that time? To go home sometimes causes an expenditure of money for street car fare—ten cents a day means sixty cents a week, two dollars and forty cents a month. The result is that they go to the moving picture show, or car rides, or something that may not be at all helpful to themselves or society. This is the danger of restricting the hours of labor; because the time outside of the working hours where the splendid conditions that prevail in Columbus are not present, where workers cannot go to proper homes but live in crowded districts, the question of occupation of time is a serious one. Women are differently constituted from men; this question employers of labor are considering.

FRIDAY MORNING SESSION
OCTOBER 27, 1917

Presiding Officer, MR. S. P. BUSH, President and General Manager of the Buckeye Steel Casting Company

MR. BUSH

It has been a long time since I have had the pleasure of coming here and meeting with the students. Possibly it may be of interest to you to know that a man who used to live in Columbus, Mr. Lilly, a graduate of Princeton University, and I gave the first lessons in Rugby football here on the campus. I don't think I would like to try another game today because football decidedly belongs to the very young. I was educated as an engineer myself and graduated from Stevens Institute of Technology. I am in sympathy with the education you get here in this University. I believe that engineering education as a general proposition can be made to equip men for work in life as well as and in some respects better than most any kind of an education. Particularly in times like these when the great questions of the world are economical rather than political, making the training of the engineer particularly fitted for working out the important problems of the world. One thing that I have felt in after years since leaving college was that an engineering education has been a little bit too narrow, in that it dealt too exclusively with material things. Now we come to see that it is not of prime importance to deal with material things alone, it is rather a secondary matter. The most important thing is the individual himself and the people collectively. Industry has grown and developed large corporations, employing large numbers of men. This has brought the problem you are now studying—the human element of engineering.

I want at this time to pay my respects to Dr. Thompson and the Faculty of the Ohio State University and to say that according to my own experience there isn't anything which they could have introduced into engineering that could be as helpful as this Congress, to yourselves and the whole country.

The program this morning consists of an address by Mr. Roberts of the Industrial Department of the International Committee of the Y. M. C. A., one by Mr. Hicks of the Colorado Fuel and Iron Company

and one by Mr. Grieves of the Jeffrey Manufacturiug Company. I would like to say that I sometimes feel that the work of this department is not appreciated as much as it ought to be. Its wonderful growth makes us feel that it should be appreciated. It has been abundantly supported by a few people. I don't think that the country fully appreciates the value and importance of the Y. M. C. A. One thing that strikes me in connection with the Y. M. C. A. particularly is the fact that they are taking up this question with an open mind; they have no special interest but they come with that splendid spirit—the only spirit that gives the best results in the end. It is a volunteer spirit. Mr. Roberts.

MR. ROBERTS

The territory I wish to cover is the work with the foreign speaking men.

Take the question of the immigrants in the United States; you have about fifteen million foreign-born in the country. That includes all the foreign-born—the Irishman as well as the Pole, the Englishman as well as the Italian. There are a large number of people who talk the English language and say they are not foreigners. An aged mother from Erin was down in Ellis Island. She came over in the steerage and was detained. She had to stay in the same place as the Poles, Italians, Jews., etc. for there is only one place for steerage immigrants at Ellis Island no matter where they come from. So she was indignant. "Why do you put me here?" "Well", said the officer, " you are a foreigner." Mrs. McCune promptly replied: "I am not a foreigner, I never left Ireland until I came here." (Laughter). Most English speaking peoples never think they are foreigners—as the Poles, Italians, etc., are. Up to the early eighties of the last century, most immigrants came from north western Europe. About that time, the peoples of south-eastern Europe began to enter. These steadily increased so that now we have about seventy-five percent of the total European immigration to the United States from that part of Europe. These are the people who give the greatest concern, for it is more difficult for them to assimilate American ideas and ideals. This would not give a nation a hundred million strong very much concern providing they were equally distributed over the nation, but they are not.

Draw a line on the map of the United States from Minneapolis in a southward direction until you touch the western section of the state of Indiana, then take your line eastward to the Atlantic, passing between the cities of Baltimore and Washington and you cut off about

fifteen percent of continental United States. In that fifteen percent you have eighty percent of the emmigrants from south-eastern Europe; and they are here in a territory which may well be called the workshop of the nation. South of the Mason and Dixon line you have less than three percent foreign-born. You will find there some foreigners from south-eastern Europe, but they are only a drop in the bucket. In the territory cut off by the lines I mention, however, it is nothing unusual to get twenty-five percent of the population of the industrial centers made up of south-eastern Europeans. In Passaic there are fifty-two percent foreign-born and add the decendants of foreign-born and you have a total of eighty-seven percent.

These people come to us from backward countries. They come with no knowledge of the English language. They have strong bodies, are amenable to discipline, willing to do what they can in the industries of the nation, but they are seriously handicapped because they don't know our langauge and they know little or nothing of the industrial development of the country. And the idea of the Y. M. C. A. is to help these men who come to this country to know about our language for practical purposes, so that they may be better workmen and better neighbors. If any of you have ever traveled in a foreign country knowing nothing about their language, you have something of the difficulties of these men. Some of you have heard the story of the Englishman as stated by Max Mueller, in his work on the study of languages. He speaks of the fact of a universal language, which can be used anywhere. Well, an Englishman, who was traveling in China, went into a Chinese restaurant to get his meals. He looked very questioningly at the meat that was served him and wanted to know what it was. So he turned to the Chinese waiter and pointing to the dish of meat, said: "Quack, quack?" and the waiter answered without changing a muscle of his face: "bow-wow". (Laughter). That is universal language, but it does not go very far. This foreigner comes from Europe and doesn't know anything about our language. He must earn a living, and I have seen men who couldn't speak a word of English go into manufacturies in Pennsylvania within twenty-four hours after landing, courageously tackling a job, willing to give their strength and risk their lives in order to make a living. They are men of courage and we come to these men and ask them to learn English and be better qualified for their work.

We have a definite program, a definite system in the work. Our purpose is to teach enough of the English language so as to enable them to speak with the boss about their job and be able to get the

things they need for living and go where they want to in the country. For this we have a special course; we have thirty lessons which is known as the preparatory course in English for coming Americans. We begin with domestic life, then we go on to his work life; and last we come to his relation to the world of buying and selling that is around him. By the time the student gets through the thirty lessons, he will have a vocabulary of about eight hundred words taught in sentence form. And if you had eight hundred words of Polish taught in sentence form about the experiences in your daily life you would be able to carry on a conversation with a man who is a Pole.

These lessons are pratical. The idea is to take a man's experiences and clothe them with a new garment of language. Take the lessons in the domestic series; they are getting up in the morning, preparing breakfast, lighting the fire, cutting the wood, eating the breakfast, naming utensils, a man visiting the home, etc. You see how we clothe the every-day experiences of the men with a new garment of language.

In the second course of lessons we go to the work life of the man looking for a job, quitting a job, injured at a job; a railroad man at work, a steel worker at work, a miner at work, etc. We help the men to know their work and talk about it.

In the third group of lessons, we teach them to connect with the world about them. The lessons are: going into a store to buy clothes, going into the station to buy a ticket, going by train, home expenses, selling and buying a lot, building a house, etc. These lessons make it easy for the man to secure the necessities of life. That is the tool we use to teach the foreigner the English language.

There are thousands of men who have learned the English language by that system. There are today thirty thousand in classes learning English by this method. Another six thousand are in classes studying for their naturalization. Of course, these men make ludicrous mistakes just as we would learning their language. An Englishman was traveling in Germany, and, in order to make things easer, he carried a little English-German dictionary in his pocket. He knew a few phrases, but didn't know many words so he often consulted the dictionary. When leaving the hotel once, he wanted to pay his bill but did not know the German word for bill; so he went to his dictionary and in his hurry mistook the word bill, what he owed, for bill, the peak of a bird, which is "schnabel", the word used for nose. He went to the clerk and said, "was ist mein Schnabel?" The waiter looked at him and said, "Gross und Roth". (Laughter). I remember a young

boy down state. While he was learning English he found many words very much alike in sound, but different in meaning. He went into a resturant to get his dinner. The waiter forgot to put a knife at and his plate so he said, "please give me a wife." The waiter happened to be an American young lady—she turned suddenly and said, "Do you want me?" (Laughter). the boy said, "No, I 'vant a wife to cut my meat." The question is always asked, can these people learn our language so that the foremen can talk to them. Our answer is that there are thousands in industry who are able to talk and to get along with their employers who have been trained in classes instituted and conducted in English by the Y. M. C. A.

Many of these men are hurt because they do not know English. I remember in a town in Illinois, down in East St. Louis, a German and Pole were working together. A loaded car pushing along a tram line was going down grade. The man shouted in Polish, "Get out of the way." The German didn't know enough of the language to understand what he was saying, so the tram car caught him between the car and the wall and almost crushed out his life. If the Pole had known enough to shout in English, "Get out of the way", and the German had known enough to understand, the accident would never have happened.

Every foreign subject should know the English language. You never will get the maximum production in industry until you have a medium of common communication between the several units making up an industry. This is the great desire of the Y. M. C. A. and it is the great desire of the employers in the United States, who feel they want this fellow to know the English language.

We also help these men to become naturalized by helping them to get their naturalization papers and thus become citizens. Thousands of them want this priveledge, they desire the right of franchise. They can't pass the examination. It is very difficult for a foreign speaking man from the south-east of Europe to understand democracy so as to pass an examination to get a vote and to use that vote as he should. He has never been taught what democracy is, has never seen democracy in action, but has been raised under a political form of government which ignores the rights of common men. Large sections of Europe from which these men come ignore all rights of the common man.

We have tools for this work also. We have a carefully prepared course in civics describing the form of government in the United States. This is done generally by bringing these men around a table. A com-

petent teacher is given them who leads in questions and discussions of the various phases of government. I have known foreigners who knew enough about the United States government but who studied at home and thought in his mother tongue and failed to express himself in English. A Lithuanian prepared by studying a book having English and Lithuanian on every other page. He could pass the examination if he could use his mother tongue but he must use English. Then the foreigner is afraid of the court and the officers, and before he can do his best he must be trained by men who sympathize with him so that he will get over his excitement and clearly answer the necessary question in the English language. This he can only do when he is properly trained by having a good leader at these round table discussions. Discuss the problems, train his ear to the questions and his vocal organs to answer the questions intelligently; make him familiar with the place where he takes the examination by leading him to the court-house. This is the work we do as a Y. M. C. A.

I know a community of ten thousand foreign speaking men, and not more than one fourth of them have the right of franchise. Now, I claim that such a place is not democratic. It is in these places that political bosses carry the wards in their vest pockets. Is that right? I say it is not democratic for seventy-five percent of the foreign people who pay taxes to be without the right of franchise. They have no voice in the government of the community. Yes, they want it. I have seen these men knocking at the door of citizenship and again and again told to go back for another six months or another year, to learn more about our government, and there was no one to help them.

When in 1906 the government of the United States gave dignity to the process of naturalization by placing the power to confer naturalization in the hands of judges in courts of record, we all rejoiced. But the government in justice to the alien ought to provide the means whereby the foreign-born could be trained in order to meet the higher requirement. This it failed to do. Previous to 1906, the abuses of naturalization were many. In many states the night before election thousands of aliens were made citizens and then lead to the polls the following day. If you want to know what the abuse of the electorate was, read the report of Colonel Roosevelt's Commission on naturalization. It was time something were done to do away with the abuses prepetrated by men who placed personal interest above the purity of the ballot. What we now most need is agencies to help the foreign-born to prepare for the examination for naturalization. We welcome the greater activity of governmental agencies in this respect. Let

both State and Federal government put into action all possible machinery to help these brothers to qualify themselves to meet the higher standard of naturalization placed by the United States government. They are calling upon the Public School to do this work, they are raising the cry that something must be done. But, gentlemen, it will never be done until the industries of the United States will throw open the doors of opportunity to the men who spend most of their hours in the shops and mines. These are the places they are going to take their standard of American citizenship from. When you young men go out into the industries of the United States you will possibly have a group such as I have described. Coming thus face to face with men you will have opportunities to impress, and to teach them what the rights and duties of citizenship mean and these men will in time be assimilated.

They need your help. A man in New Jersey, applying for his naturalization papers, when asked, "Mention three states in the union," answered promptly, "New York, Jersey City and Hoboken." Another man when asked: "What is the constitution?"—answered, "The fundamental law of the land." The Judge turned and asked, "What is fundamental?" He did not know and was dimissed and given more time to prepare. Another man was asked to bound the state of New York. How many present can do it? An alien once asked me: "Is it fair for a Judge to ask questions of aliens which a native-born cannot answer?" The only thing that I could tell him was: "Get into a class, prepare for the examination for you cannot know too much to exercise the sovereign power conferred upon you," Every man anxious to qualify will, if he does not know enough, go to school to prepare and learn more.

Another part of our program is lectures and motion pictures. Take the city of Chicago, they have been projecting these lectures there. I have here a report from the secretary who conducted this work. He states that they reached in the neighborhood of thirty thousand people. The lectures were given in the several parks and on the street corners. Try it out, run up a sheet, put the machine into action and show those people what America stands for, and you will never lack an audience.

I met an Italian in New York City who had been in this country for thirty years, but couldn't talk English and didn't know anything about America save what he saw in that city. The immigrant has no idea what the geographical area of America is.

I happened to be an immigrant, a good old mother came to me and said, "You are going to America. I wish you would remember me to William, just remember me to William!" I asked, "Where is William?"–"In Pueblo." I was going to New Haven, Connecticut. (Laughter). These people have no idea of the extent of the country, no idea of the opportunities of the country. We believe that a man when he casts his lot among us ought to know something of the privileges and the opportunities of an American citizen.

In an article written on American life recently, the author concluded that America was not a nation and that the various peoples coming to the United States were not assimilated. How can they be unless missionaries go out to tell them what the promise of American life is, what the lure of American life is. These people ought to be made to feel that there is something more in American life than the dollar, and the industries of the United States should be made a stepping stone to that knowledge.

America has its ideals. The founders of this Republic had ideals of liberty, equality of opportunity and democracy which we dare not forget. They sacrificed their lives and wealth for them and they should be dear to us; and if these ideals obtain today they should be a stimulation to every man coming to the United States. America has been a good place for immigrants of past generations, and it is now a good place for these millions and they should know it.

We must have a definite program of work for assimilating foreign speaking men and women in the United States. Some industries have ladies working in this direction among their women. Down in Colorado they are doing this. Clubs are organized among the women. I was in New Haven when they organized a club among the foreign women and what do you think they called their club? "The Teddy Roosevelt Club." (Laughter). Every mother was eligible. After founding the mother's clubs in a foreign settlement it is usually found necessary to start a kindergarten. The mother's meetings and the kindergarten go side by side. The lessons and discussions given these mothers must be practical. They mostly deal with the domestic life of the mother, and the leaders do not forget amusements.

An article in the Literary Digest of last week, says, 'This America is not a nation, only a conglomeration made up of units bound together—it is but a rope of sand.'' A criticism like this makes us think: How much truth is in it? How can it be cured? Only by treating your brother as your friend, we must deal justly with him if he is to be one with us in this nation.

I was down in Bayonne, New Jersey, lately. I went into the foreign quarters where they recently had that upheaval. As the guide took me along the streets the sight that met my eyes was terrible. Busi-houses simply gutted either by law or lawlessness. Did you read the fourth request those men put up to the company? A simple appeal from the heart for a square deal; to be dealt with like human beings and not be cuffed and cussed as if they were some beings of an inferior order. The Hungarian and the Italian ask for that. They are men just the same as you and I; made by the same eternal God; they have a sense of right and justice. You cannot treat them as dogs in the industry of the nation—if you do you must take the consequences and they will be terrible. The only thing the foreign-speaking man wants is a square deal. Now you young men can help in the process, help in the work—let the message rest in your hearts, and, when the opportunity comes to deal justly and kindly with the foreigner, be not wanting, for in doing this you serve not only industry but also your country. I look upon the strife going on across the ocean. Have you observed what is going on there when nations fight for their very life? To every man in the land the question comes: "What are you doing for your country?" "Are you worth dying for?" When peace is in the land that question is never asked. There are thousands of men in the leisure classes today who are now asking themselves that question. The greater the strain is, the more urgent the question: "What are you doing for your country?"

Mr. Astor thought fit to leave the city of New York and take out naturalization papers in England. He has a perfect right to do this. According to the fundamental law and creed of the United States, everyone has a right to choose his citizenship. We can't say anything about Mr. Astor. We open our doors every year to fifty thousand foreign-born men who swear allegiance to our country. Mr. Astor had the right and he lived in peace. But when the day of stress came on England the question came to him: "What are you doing for your country?" and he answered it by doing his "bit".

An American heiress married a foreign count. They lived in luxury and ease and no one said aught; but when the country was torn in battle the question came to them: "What are you doing for your country? The count answered the call in the trenches, the beautiful castle was turned into a hospital and the heiress, true to democratic ideals has put on cap and gown to wait on the wounded.

There are fifteen million foreign-born, seventeen million sons and daughters of foreign-born, making a total of thirty-two million de-

scendents of the foreign-born parents in the land. They need wise guidance in their quest of American standards—they enter the melting pot and before they enter they need to be molded and shaped according to ideals and ideas that have made America what it is. If this is done purposefully and persistently the product of the melting pot will give us little trouble.

I tell some of my friends that if they hope to enjoy heaven and feel at home there, they must get acquainted with some other nations than their own. For you know what the Bible says—that all nations are represented there. Some good people believe that heaven is for those who talk the English language. I want to tell you that St. Peter sitting at the gate knew many languages before he learned English. (Laughter).

If you want to feel comfortable when your Father calls you to glory, get acquainted with the nations your Father has brought to your door. Every one of them is your brother. Organize and carry through a community meeting and bring together men of all nations in the town—let every nation take a part and you will be astonished how human these people are and how very much like every one of us is the foreigner.

These foreign-born are not in America by accident—they are here by God's plan. It is God's way to bring out a better manhood for tomorrow. America needs these men. When the strain comes on this Nation, and come it will, we want the foreign-born to share it with us. When the day of stress and trouble comes it will test every fiber in the nation's life. If the test finds us wanting and the dreams of our fathers vanish as the mist of morning, then you can set back the hand of- time five hundred years and dig a deep grave for the hope of human ity. Gentlemen, we want to make that impossible in America. We can do it by making ourselves one nation, leading the world in the idea of a brotherhood of nations to safeguard the hopes and ideals of men, and which have found their highest realization in that part of the earth known as the United States of America.

Mr. Bush

Ladies and Gentlemen, we have heard a splendid address. There can be no doubt left in the minds of any as to the fact that that particular phase of engineering, human engineering, as presented is a tremendously vital thing. This sympathy with human kind is one of the great things which this department of human engineering is going to impress upon the minds and hearts of those who are prospective

engineers. A part of this program is set aside for discussion. We will take a moment for this at this time. I will ask Mr. Rindge to start this discussion.

MR. RINDGE

I don't know that I can add anything. One of the objects of the Y. M. C. A. is to interest the college student in volunteer service in teaching the foreigner the English language. I understand there are a lot of men here in this University doing some of this work and they would know more about what was done last year. It is tremendously worth while right here in Columbus. If we have time, and I think we have, I would like to ask Dr. Roberts to take three or four minutes right now to answer questions. Namely this: How can we as students actually teach a class of foreigners English. Probably we have a dozen different kinds in a class in a city. Mr. Roberts has invented a system of teaching the foreigner English throughout the country.

MR. ROBERTS

Learning a language is training the ear by training the vocal organs. The organ of language is the ear. The vocal organs must adjust themselves into a peculiar sound or a modification of sound, pertaining to one language. You may ask, "What is a language?" "It is modified sound."

If you want to try that out get a Pole, let him talk, hear the sound—sometimes quick, sometimes high, sometimes low. You ask how do we teach—just the same as we teach the child. The child hears the word Mama, and Da Da. One day it says Da Da—the mother jumps to the phone, tells John to come home quick, baby is talking. (Laughter). What is the process—The little chap is using his vocal chords. In teaching a group of Italians I do it in just that way. We have lessons, form lessons. Generally speaking, the subject matter deals with the common everyday experiences—Getting up in the morning—when you get up you want to know the time—for it is a serious thing to get up too early. (Laughter). You put on your clothes and go downstairs. I have an interpreter tell them what they are doing. They watch my lips. (Here Dr. Roberts gave an illustration of just how he pronounced the words and how they would be repeated by the foreigner), saying, I awake from sleep—I open my eyes—I look for my watch—I find my watch—I see what time it is, etc.

The third step is that every lesson is constructed along lines which make it easy for the pupil to learn it. Based on these three principles

has been developed the first group of lessons in English for foreigners. As I said the group comprises thirty lessons, divided into three series. Domestic, Industrial and Commercial. In teaching the foreigner you must know how to act, know how to smile, know how to laugh. Call him by his name, never call him by a number, say twenty-three. (Laughter). Treat him as your brother, call him by name.

MR. BUSH

I might suggest that what is needed by the large industries in this country today, is about a million engineers like Mr. Roberts. The engineer is going to be as he is pretty largely already, the chief executive in industry in the future. I can tell you from experience, covering a good many years, starting at the very bottom, that it is going to be necessary for the executive to have a special kind of sympathy and ability such as Mr. Roberts has. I want to say as a matter of encouragement to you that there are hundreds of splendid positions open to you.

Now the next address on the program, is by Mr. C. J. Hicks, of the Colorado Fuel and Iron Company, on "Industrial Betterment Progress". I never had the pleasure of meeting Mr. Hicks, but from the very beginning of their efforts there I have been receiving their literature describing their work. I can say I believe the work they have undertaken is probably the largest of the kind ever undertaken in the world. It is a great co-operative movement. I am sure it is most fortunate that we are able to have such a man as Mr. Hicks to tell about that great work. I have great pleasure in introducing Mr. Hicks.

MR. HICKS. (Introductory Remarks)

Dr. Roberts has warmed our hearts and thrilled us by telling of the work as carried out by the Y. M. C. A. for foreign speaking men. One reason for its success is because of the favorable attitude on the part of the employer. I have been asked to tell about the social betterment work of the Colorado Fuel and Iron Company. It is typical in many ways of the work done by other great corporations.

SOCIAL AND INDUSTRIAL DEMOCRACY IN THE COLORADO FUEL AND IRON COMPANY

C. J. HICKS, Executive Assistant to the President

1. THE COMPANY AND ITS EMPLOYEES

The Colorado Fuel and Iron Company has a force of from 11,000 to 12,000 employees, distributed as follows:

1—Approximately one-half are employed at over twenty coal and iron mines and coke ovens of the Company in southern and western Colorado and in Wyoming.

2—A group of somewhat less than one-half are employed at the Minnequa Steel Works at Pueblo and at the two quarries serving the Minnequa Plant.

3—The remainder, or approximately 1,000 employees, are distributed at the timber properties, stores department, in the railroad service and at the General Office in Denver.

2. THE C. F. & I. BETTERMENT PROGRAM

This Company has for many years been one of the leaders in social and industrial betterment work, but a little more than a year ago it adopted a policy of co-operation with its employees in these matters that differentiates it from other companies.

Much of the betterment work in which corporations have been interested has been ineffective, either because it was regarded as an attempted substitute for justice or because it was one-sided and paternalistic, and did not enlist the interest and co-operation of employees. The Colorado Fuel and Iron Company is in the midst of a program of co-operation with its employees in matters affecting social and industrial betterment that is comprehensive and thorough enough so that it should assure success.

This program is based, fundamentally, on fair treatment as to wages and working conditions. The wages paid are as high, or higher than those paid by competitors, and they are subject to re-adjustment, as to wage earners, through their own representatives, and as to salaried employees, through the Salary Committee. The hours of work for miners are regulated by law; and the hours of steel workers are the same as those prevailing in the steel industry elsewhere. Each employee is re-

quired to take one day's rest in seven except in cases of real emergency.

The different lines of betterment work built upon this basis may be grouped as follows:

First: The Company will, as rapidly as possible, expend whatever money is necessary to provide sanitary and safe working conditions, modern wash and toilet rooms, and such living conditions as will make a real home life possible.

Second: Through the Industrial Representation plan every wage earner is assured that he need not submit to any injustice; any greivance of his will be considered and adjusted, and the way is open to appeal up to the President of the Company, or to the State Industrial commission.

Third: The Company covets a real partnership with its employees in all that pertains to their living and working conditions; and to this end the various joint committees provided for in the plan are being developed. It stands ready to co-operate with social, educational and religious organizations of its employees, either finanically or in any way that will make their work most effective.

3. Social Conditions at the Mines

The attention of the public has been drawn, through various reports, to the group of the employees in the coal and iron mines of this Company, but the conditions in these camps are not all what one would expect to find if he had read the sensational stories circulated in the press throughout the country. In August, 1915, while in the employ of another company, I made a tour of the C. F. &. I. properties, and, with every opportunity for a thorough investigation, I was unable to find any conditions that afforded a real basis for the widespread charges of tyranny and neglect. This agrees with the findings of several others investigators who have, within the past two years, made independent social surveys of these camps.

The living and working conditions compare favorably with any group of camps in the East. The houses are largely of the most modern design; the camp sanitation is carefully looked after; pure drinking water is provided; the medical service is of the best; the Company stores provide most of the food supplies at fair prices and in open competition with peddlers and adjacent stores: the much heralded "stockade" is a fiction; the schools rank with any in towns of equal size in the State; and the camps are occupied by contented families of many nationalities, among whom poverty is almost unknown. The most unsanitary and unsightly places in these camps have resulted from allow-

ing the miners, in the early days of coal mine developement, to build their own houses. In many cases these houses were nothing more than shacks, although occupied in most cases by faithful and loyal employees. As the only method of insuring uniform sanitation in the camps, it has been necessary for the company to purchase and destroy these shacks, and they are being replaced by modern cottages.

4. Industrial Democracy

The basis of co-operation between the Company and its employees, which was adopted over a year ago, has been commonly called by the public, "The Rockefeller Plan". The Sociological Department, which for some years had supervision of the Company's welfare work, has been merged in a comprehensive plan of social and industrial betterment, for which every officer of the Company is held responsible, and in which it is sought to enlist the co-operation of every employee.

The Industrial Representation Plan, as it is commonly called, put into effect by vote of the employees and directors of The Colorado Fuel & Iron Company following a visit to the Company's mines in September and October, 1915, by John D. Rockefeller, Jr., is based upon and is a development of a system of representation adopted by the Company several months earlier. It is the outgrowth of a suggestion from Mr. Rockefeller that some machinery be provided so that every employee might have easy access to the officers to present any grievance or any suggestion as to working conditions. Under the system first inaugurated, the miners at each camp elected representatives in proportion to the number of wage earners. These representatives were empowered to settle with the officers of the Company any grievances between the corporation and its coal miners.

Following the adoption of the Industrial Representation Plan the representatives elected under the earlier system held office until January 8, 1916, when a new group of representatives were chosen, as provided under the Industrial Constitution. The system put into effect applied at first only to the coal miners in Colorado. Soon after its original adoption, however, it was extended to the Company's iron mines in Wyoming.

Under this Plan the employees are given industrial representation through delegates of their own choice. The men and the Company signed a written contract embodying wages, hours of service and other vital factors. The Company in this agreement also binds itself to furnish powder and domestic coal to its workmen substantially at cost,

to fence miners' houses and to rent and furnish light at certain specified rates, and to provide bath houses and club houses as the need of them becomes manifest.

Under the Plan of Representation, employees in each camp are entitled to one representative for every one hundred and fifty wage earners, with the further provision that the representation in no camp shall be less than two. Elaborate precautions are thrown about the system of nominating and electing these representatives, with a view to guaranteeing the employees a free choice by secret ballot without influence from the Company's officers or anyone else.

The mining camps of the Company are divided for administrative purposes into five districts: The Trindad District, the Walsenburg District, the Canon District and the Western District, in Colorado, and the Sunrise District, in Wyoming. The Plan provides for the holding of district conferences between the employee's representatives of a given district and Company officers designated by the President. At these conferences free discussion of all matters of concern to the Company or its employees is guaranteed. In addition to these district conferences there is an annual joint meeting of all the districts held in December.

For the purpose of securing more intensive consideration of specific matters of welfare, each district conference selects the following Committees, upon which the representation of employees and of Company officers is equal:

(a) Joint Committee on Industrial Co-operation and Conciliation; composed of six members.

(b) Joint Committee on Safety and Accidents; composed of six members.

(c) Joint Committee on Sanitation, Health and Housing; composed of six members.

(d) Joint Committee on Recreation and Education: composed of six members.

The duties of these committees are such as are indicated by their titles. The Committee on Industrial Co-operation and Conciliation, in particular, is entrusted with the task of preventing and settling industrial disputes and maintaining order and discipline in the various camps.

In this work of adjusting industrial controversies, the Plan provides elaborate machinery by which an employee with a real grievance is given every safeguard for his rights. The Company deals directly with

the employees through the work of the President's Industrial Representative, whose duty is to go from one camp to another, on regular visits, or at any time in response to summons from either side to any controversy. It is provided that an employee believing that he has a grievance shall appeal first either in person or through his representative to his own pit-boss or superintendent. Failing to obtain satisfaction from that source, he may summon the President's Industrial Representative, who shall hear both sides of the case and act as mediator. If after this the employee still thinks he has been unfairly treated, he may appeal to the superior officer of the company up to the President. Other methods of settling disputes are provided including arbitration by the District Joint Committee on Industrial Co-operation and Conciliation, an appeal to an umpire, or an appeal to the State Industrial Commission.

The Company guarantees that there shall be no discrimination by the Company or its employees on account of membership or non-membership in any society, fraternity or union. For the protection of employees' representatives against unjust treatment, it is provided that they shall have the same right of appeal as other employees' and that they may ultimately appeal to the State Industrial Commission, with the assurance that the Company will make such reparation as that Commission may deem just.

The Company reserves the right to discharge employees for cause, but, in accordance with an agreement in the Industrial Representation Plan, it has posted at all the mining camps a list of the only offenses for which a man may be discharged without notice. For any other offense the delinquent employee is entitled to receive warning that a second infraction may lead to his dismissal.

But the settlement of disputes is only one of the lines in which the co-operation of employees and their representatives are sought. Working conditions are bound to be greatly benefitted by the work of the Committees of Safety and Accidents. And through the Committees on Sanitation, Health, and Housing, and the Committees on Recreation and Education, it is planned to quicken a sense of responsibility and awaken interest among the employees in all that affects the living conditions in the Company's camps.

The employees are given the right to hold meetings on the Company's property, to employ check-weighmen and to purchase supplies where they please. The corporation assumes the entire expense of administering the Industrial Plan. Employees' representatives at-

tending meetings have their expenses paid and are reimbursed for the working time lost. The Plan provides, however, that employees may pay their own representatives if they prefer to do so.

The Company has begun the publication of a quarterly bulletin, with occasional extra issues, as a means of communication between officials and employees.

An Advisory Board on Social and Industrial Betterment has been appointed by the President, composed of eight officers of the Company, under the chairmanship of the President's Executive Assistant, who has supervision of the Company's policies in this respect.

5. Extension of Plan of Steel Work Employees

The Industrial Representation Plan thus outlined was applicable at the outset only to the employees in the coal and iron mines but at the Minnequa Steel Works, Pueblo, a similar Plan, adapted to the conditions of the steel industry, has during the past year been put into operation. For the purpose of this Plan the Steel Plant was divided into nine divisions, each of these divisions being entitled to from two to seven representatives, depending upon the number of the employees grouped in the division. An election of the Steel Works' employees representatives was held January 11, 1916 and twenty-six men, from among the different departments, were selected. Two representatives were also chosen at each of the two stone quarries on the same date.

The Plan was first approved by these Representatives and later adopted by the steel workers. Joint Committees have been organized and Joint Conferences are held at least once in four months.

6. Three Important Features

At each of the Company's properties several copies of three different placards have been posted. These placards emphasize three of the most important features of this Plan.

(a) A placard giving the names of all of the employees' representatives and also giving the personel of the various Joint Committees. This is a constant reminder to the employees of the channels through which the various matters in which they are interested may be taken up.

(b) Another placard contains the rules as to working conditions. These rules have in each case been approved as fair by employees' representatives.

(c) A list of offences for which an employee is subject to suspension or dismissal without further notice. This list of offenses has also

been approved by the employees' representatives and no employee can be summarily dismissed unless he has committed one of the offenses on this list. Arbitrary action, which frequently results in injustice, is thus no longer possible.

7. An Unqualified Success

This experiment in Industrial Co-operation has now been in operation for over a year and the results afford a fair basis for an estimate for its success. At the time of its adoption there were representatives of both capital and labor from outside the Company, who freely predicted it would be a failure, but both officials and employees of the Company entered heartily into the spirit of co-operation and partnership embodied in the Plan and the results have been most satisfactory.

As to the adjustment of grievances it is interesting to note that over fifty grievances have been submitted to the President's Industrial Representative, and this does not include many of minor importance that have been adjusted locally. In every case these grievances have been fearlessly investigated, and a settlement has been reached that has been accepted as fair by the representatives of the employees. Some of these grievances were based on misunderstanding; others were based on injustice, as for instance, the unfair discharge of an employee, and in such a case the employee was promptly and fully reinstated. There has been perfect liberty of expression and no man has suffered because of having voiced his grievance or that of a fellow employee.

During the year wages have been increased twice at the Steel Works and once at the mines and each of these wage adjustments has been made in conferences with the employees' representatives.

Joint Conferences held throughout the year have offered opportunity for fair and full discussion of living and working conditions and have laid the foundation for confidence and good will.

The Joint Committees provided for under the plan have been fully organized and have held from one to seven meetings each.

In the meantime there has been a steady improvement in physical conditions at the camps; much money has been expended in erecting dwelling houses, Y. M. C. A. club houses, bath houses, and garages in fencing nearly all of the employees' homes and in otherwise making these camps attractive and homelike places.

Such in brief outline are the outstanding features of the program of Social and Industrial Betterment to which the Company is pledged. This program is an honest attempt to establish fair and friendly rela-

tions between the Company and its employees, not on the basis of paternalism, but on the basis of partnership and industrial democracy.

The experience of the year has lead the President to make the following statement in his annual report to the stock-holders: "From the standpoint of both management and employees, THE INDUSTRIAL REPRESENTATION PLAN has been an unqualified success".

Mr. Bush

Now we have heard this exposition of Mr. Hicks concerning the plan carried on by his company. I would say it is the biggest and most comprehensive thing ever undertaken. The plan itself is a wonderful piece of engineering work, to devise and put in operation—a great task in itself. I want to emphasize one point I believe Mr. Hicks was trying to drive home. While the plan may be ever so wonderful and ever so comprehensive in all its features, it wouldn't be really effective in accomplishing the results unless back of it all was the good purpose. In other words, if the heart was not in it; we all know that any activity or any project has small chance of success unless the heart is in it.

Now I think we probably would like to ask some questions of Mr. Hicks.

Question. If a man is discharged can he get employment in another department.

Mr. Hicks

Let me say a man is not discharged by the company, but when he leaves the company he is through. If a man is discharged he is no longer discharged by the company—everybody from the president down is responsible for that discharge.

Question. What are the eleven offenses that will cause the discharge of employee?

Mr. Hicks

1. Violation of Any Law:

Special attention is called to the following:

(a) Carrying concealed weapons; fighting or attempting bodily injury to another employee; drunkenness; bootlegging; habitual use of drugs; conduct which violates the common decency or morality of the community.

(b) Offering or receiving money or other valuable consideration in exchange for a job, better working place or any advantage in working condition.

(c) Stealing or malicious mischief, such as destroying or hiding any property of other employee or of the company.

(d) Inhuman abuse of live stock or negligence resulting in their death.

2. VIOLATION OF THE FOLLOWING SAFETY RULES:

(a) Carelessness in regard to accident and safety of fellow workmen.

(b) Riding on standard or narrow guage equipment or on any moving machinery where not assigned.

(c) Running up blocks on cranes.

(d) Violation of rules governing repairing or oiling of moving machinery.

(e) Failure to wear safety goggles that have been provided.

(f) Smoking within prescribed limits at Wire Department, or other places where such practice is forbidden.

3. INSUBORDINATION (INCLUDING REFUSAL OR FAILURE TO PERFORM WORK ASSIGNED) OR USE OF PROFANE OR ABUSIVE LANGUAGE TOWARD FELLOW EMPLOYEES OR OFFICIALS OF THE COMPANY.

4. ABSENCE FROM DUTY WITHOUT NOTICE TO AND PERMISSION FROM SUPERINTENDENT OR FOREMAN, EXCEPT IN CASE OF SICKNESS OR CAUSE BEYOND HIS CONTROL OF A CHARACTER THAT PREVENTED HIS GIVING NOTICE.

5. HARBORING DISEASE THAT ON ACCOUNT OF HIS OWN CARELESSNESS WILL ENDANGER FELLOW WORKMEN.

6 CHANGING WORKING PLACES WITHOUT ORDERS OR PROWLING AROUND THE WORKS FROM ASSIGNED PLACES.

7. FALSIFYING OR REFUSING TO GIVE TESTIMONY WHEN ACCIDENTS ARE BEING INVESTIGATED, OR FOR FALSE STATEMENTS WHEN APPLICATION AND PHYSICAL EXAMINATION IS BEING MADE.

8. NEGLECT OR CARELESSNESS RESULTING IN DAMAGE TO RAILROAD EQUIPMENT, OR NEGLECT OF CAR DROPPER TO PROPERLY SET BRAKES ON RAILROAD CARS IN HIS CHARGE.

9. ROBBING RAILROAD OR NARROW GUAGE CAR JOURNAL BOXES OF WASTE.

10. Wilful Neglect in Care or Use of Company's Property.

11. Obtaining Material at Storehouse or Other Assigned Places on Fraudulent Orders.

Mr. Kellog

The question is whether it pays in dollars and cents. Such a course may react on the productive power of labor.

Mr. Hicks

If it is right and fair and just, I don't see how you can reduce it to dollars and cents.—(Applause).

Dr. Thompson

This is my first opportunity to be in this meeting, and, on behalf of the University, I desire to express our sense of appreciation towards those who have come here to participate in the program probably at their own great inconvenience and to our service. Aside from that I am pleased to hear the discussions this morning. I am interested in seeing the spirit that is manifested here, and expressed in this way. I have long held the conviction that a permanent form of business ought to be all righteous,—if I may use that word. For what is essentially right and what is true will be the things which will abide. I am glad to see this element come out in the discussion here this morning, and to hear of this great company and leaders in industry making sincere efforts through co-operation for the things that are right and just. One of the great fundamentals of the United States government was the establishment of justice. There can be no justice but what is associated with what is right. The administration of what is right must be just. The idea of human brotherhood is the great conception here and I should have that emphasized very strongly. I congratulate you on these things which are coming steadily out. The future of America is the future in which there will be a justice and an equality of human brotherhood, a regard for the other man. As these things come some of the things that are not right will steadily disappear from the conduct of business. Integrity of character and the administration of justice are the foundation of a permanent and prosperous industry.

Mr. Bush

Our next speaker will talk to you about the handling of men. Sometime ago I said that there was a demand for a million engineers

that had the capacity and the personality of Mr. Roberts. I was not just making that statement to say something extravagant or sensational. It wasn't anything of that kind. That expression came only after the soberest of thought. It is because our own industry has developed in such large units nowadays. Industry is so complex that the human element is the prime consideration, the most important thing in industry. We finally come down to the handling of men. This subject Mr. Grieves is going to talk about. The Jeffrey Manufacturing Company is one concern which has made every effort along this line bringing about as best they can a just and fair relation between their employees and themselves. I have the pleasure of introducing Mr. Grieves.

THE HANDLING OF MEN

By W. A. GRIEVES, Assistant Secretary, The Jeffrey Mfg. Co., Columbus, Ohio

Present day industrialism is marked by the rise of an unmistakable desire for better things. The air is charged with the spirit of a broadened conception of the rights of others. A glowing ambition has taken possession of our industrial activity. It is not ambition confined to the limits of sordid self-aggrandizement, but has as its aim the fundamental good of the class. It is the culmination of the effect of the various influences that have been at work for many decades, and the practical working out of its ideals is one of the best evidences we have of our industrial and social security. It is the humanizing of industry. We are proud of it. Its coming increases our faith in each other, although it has to climb over rugged walls of selfishness and indifference in reaching us. It may be that this selfishness and indifference has given rise to the need to which this spirit is an immediate response, and consequently the desire to improve conditions appeals not only to our sense of fraternity, but also to our good business judgment.

At the very outset, therefore, we are confronted with the question, what is the objective? What are the means to be employed in reaching that object? Are the methods thus far adopted in line with ideas of permanency? That the pupose is intended to do good, would not be going much farther than stating a platitude. That is not enough. Intelligent service must have feasible aims. Further than that, even if the aim is definite, and we are agreed that it is desirable, it is important to know by what methods our purpose is to be reached. We may be perfectly in harmony as to the result to be obtained, yet there may be honest difference of opinion as to the feasibility of indicated methods.

Human engineering is an agency that has come into being as a result of demands made for the improvement of industrial conditions. It is a part of the crusade for the advancement of ideals of the people engaged in our great army of industry. It is an honest desire on the part of the better elements in our industrial life to emphasize the slogan that, "Industry is for humanity, and not humanity for industry."

As engineering students you are preparing yourselves for positions

of responsibility in the great field of industrial activity. You are mastering the fundamental principals of the problems which you will be called upon to solve in so far as they relate to your chemistry, your metallurgy, your structural engineering, and the many other fields that you will enter; and now you are setting aside a portion of your time to study what is in our opinion really the most important unit of your whole course—human engineering.

One of our biggest manufacturers has made the statement that there were three fundamental elements entering into the make-up of industry—men, money and machines. He has said that there is very little difficulty in getting money; that it was not hard to get machines; but that it was a tremendous task to get men. But after onr twelve years experience in handling men, we are convinced that, while it is difficult to get good men, we think that the big maunfacturer did not go far enough. He should have added: "It is still a greater problem to keep men after you have once hired them". And this is the particular phase of this subject of human engineering to which we wish to direct our discussion.

To get before you the magnitude of the problem and of how vital it is in business today, we would like to mention a recent investigation that revealed a remarkable condition. We refer to this because it lies so closely to the very foundation of economic production. It is a rather recent factor in industrial development, and is so full of possibilities that you will do well to know as much about it as is possible without having been directly engaged in the actual work itself. It is a question of labor turn-over. We wish to discuss it for the reason that it posesses so many elements directly concerned with the human factor and the handling of men.

To get the subject before us as vividly as possible, let us suppose you have finished your college work. You are ready for a job. You want as good a job as you can get. You apply to a manufacturer who, we will say, employs 2200 men. You tell him that if he will employ you, you will in a few years, by methods of greater consideration for the human element among his employes, reduce the cost of maintaining his force, in round numbers, at least one hundred thousand dollars a year. If he were the average employer, of course he would not believe you; but if he were an employer who knew his business, he would not hesitate a moment in considering your offer seriously; for these figures have been verified in an investigation made about two years ago in which the experience of a large number of firms was tabulated.

About seven years ago to maintain a force of 2200 employees,'a certain firm was hiring on an average of 5000 employes each year. It began a systematic study of the causes entering into this tremendous turnover. It was convinced that something was wrong. It prided itself on having a fairly scientific method of selection. It had gone on the assumption that if a proper study were given to the placing of men at the begining of their service, the employment problem was handled as best it could be. But it had not analyzed correctly. It had led itself into the belief that if the slant of a prospective employees' eye was at a certain angle, or his ears drooped at a degree scientifically correct, or that he had the proverbial high forhead, or that his jaw did not receed too abruptly, it had done all that was necessary in determining what was desirable in the way of selection, and consequently its problem of handling men was solved.

But you see this firm was trying to get a solution of its difficulty by studying an effect in the way of an excursion into the realm of physiological psychology, when it should have been looking into the real cause of its having to pay so much attention to selection. It finally occurred to it that if more interest were shown in the causes for men leaving its employ after they were hired, it would be more profitable than being so much concerned about selection, important as that phase of industrial management is. So instead of looking upon the employment office as being such an asset, they began to think that it might be, in view of its failure to locate the real reason, a sort of liability. Results proved the logic of its reasoning. It maintained that if John Smith came into its employ and in a short time left, there must be some reason for his quitting. In fact he did quit to the extent of nearly three times every year. In other words the whole force, numerically, turned over about three times annually. What was the cause? It could not be wages; for it had already learned that if it were to have competent men it must pay the best rate. It could not be that the general attitude of its organization was such as to produce a condition of this kind, for the spirit of the firm was good above the average. It was not because of lack of sympathetic understanding on the part of the management, for this general relationship had always been of the true spirit of mutuality.

A systematic study of the causes revealed the fact that this wholesale shifting was largely due to conditions that really concerned the relationship of the men among themselves. There were abuses existing in the various departments of which the management had not been aware. There had not been any general effort exerted by the foreman

to deal with the men on the basis of mutual understanding. If an employee erred in the performance of a task, the old idea of discharge was resorted to. The realization was not apparent that the Company had a large investment in the men discharged. There had not been any getting together of the heads of departments so that a broader understanding of their respective difficulties could be acquired. There had been very little attention paid to the troubles of the employees as related to their home life. No systematic study had been made of the cause of accidents and of how they could be prevented. There had not been any attempt to stimulate within the organization the spirit of aggressiveness as it could be applied to the employees initiating and developing enterprises for their benefit. And yet, up to that time, this firm was counted among the more progressive.

After a systematic program had been conceived and put into operation, the turnover began to diminish. A thorough study of the causes of accidents was made. A hospital with a trained nurse and a physician was established. Foremen's meetings to discuss methods of closer co-operation were begun. If an employee did not make good in the department to which he had been assigned, he was given a trial in another at different work. If he was slow to learn, greater patience was exercised in teaching, going on the scientifically good reason that if he was let go, the opportunity of getting any one better was not probable. Juducious interest was taken in the home life of employees; not to the extent of exceeding the limits of desirability, but in all cases where real helpfulness would be appreciated. Employees co-operative enterprises, entirely under the control of themselves, were started. Full freedom in the outline of procedure was given. When any change of methods, effecting to a degree the work of the men, were made, the opinions of every man were solicited. Each employee understood that if he had a suggestion to make for the improvement of a certain condition, it would be given honest consideration. Many other activities were started of a co-operative nature that proved beneficial both from a physical and financial standpoint. And what was the result? Inside of six years the number hired to maintain the average force of 2200 was reduced from 5000 to 1500.

Thinking that its own experience might not be a fair one from which to draw conclusions in the matter of labor turnover, this firm made an investigation. It approached forty different firms in similar lines of industry for the purpose of getting their experience in this matter of turnover, only twenty of which were able to furnish definite data. The investigation revealed the fact that to maintain an average

force of 44,000 men in these twenty concerns for the previous year, 70,000 were hired. According to fairly definite data secured from insurance statistics and governmental reports, together with the experience of a number of the leading employment experts of the country, about forty per cent of this turnover may be accounted for. To be specific, about one per cent of any industrial force or group will die; five per cent will change because of sickness; ten per cent will remove on account of conditions of climate and family troubles; and with a 25 per cent allowance for defective selection on the part of the employment department, we have forty per cent of the total accounted for. This would seem to be a very liberal allowance and should cover the unavoidable contingencies. But after we have substracted the forty per cent, we have remaining sixty per cent or about 42,000 of the 70,000 to be reckoned with. What has been the cause of their instability? These are some of the problems with which you as engineers will be confronted. How are they to be solved?

From the standpoint of waste in production you will readily appreciate the necessity of searching deeply for the reason, for the field of opportunity that is open to you for your best efforts is wonderfully inviting. The fact that millions of dollars are unecessarily being spent annually in the changing of industrial forces, indicates not only the necessity of scientific selection, but also of greater humanity in handling. The call for men with broad intelligence and an understanding of the human element in shops and factories is urgent. Business men are awaking to the fact that the so-called labor problem is not so much of a problem after all. They are beginning to see that it expresses itself more in the form of a condition, and are convinced that when the causes of the conditions are removed, the problem adjusts itself. What we need most is men educated to understand the human factor. The good business sense of our manufacturers is not going to allow them to continue to ignore the leak of millions each year through a source that can be prevented. What they need most today is men so trained for leadership that the less intelligent can be lead to a higher plane of thinking and working.

Manufacturers in the past have been spending large sums of money to educate their sales forces, to advertise their product to the public, and of course the results have been astonishing. But they are not any longer confining their instruction to their sales forces. They are carrying their campaign of education into the shops. And why shouldn't they? The same methods by which a higher intelligence is conveyed to a sales force can be applied with equal profit to the pro-

ducing end of every business. The splendid propaganda that is being carried on by the National Association of Corporation Schools is an evidence of the determination on the part of employers to bring a higher standard of intelligence to the man at the bench and machine. And the plan that is being used is honest and economically sound. The employer knew that any method adopted must be mutually beneficial; for these are days of honest dealing. Men who expect to remain in business know that mis-representations react; and they do not recognize this necessarily for any particular moral reason, but for the scientific reason that it is good business. Business is learning that a policy of getting all it can and giving as little as possible in return, does not pay. It has begun to recognize the truth that to get more it must give more, and that the way to ultimately get nothing is to give nothing. The mutually profitable policy, therefore, is the only one that will last, and the mutually profitable plan of dealing with men is the only one that will endure.

Undoubtedly the first plan of attack is through the medium of education. If the employee will not co-operate to bring about a better condition, put it down to lack of higher ideals. The absence of high ideals is the result of ignorance, and ignorance is nothing more than lack of education, and the very best method of getting higher educational ideals is through the medium of publicity. How important it is, then, that the men who are to help in the improvement of conditions be men who are trained in the broadest way possible. The trouble has been that the selling and engineering end of industry has called all our trained engineers, to the very great detriment of the producing portion. What we need as leaders among our shop forces are men of higher intellectual standing. The time is coming, in fact it has already arrived, when the shop foreman will be required not only to be a shop trained man but also a college trained man. It requires just as big calibre men to conduct and handle the shop forces as it does the sales or engineering. In the past we have not thought so, but it is none the less true. Is it any wonder that we have labor disputes? Is it any wonder that men have misunderstood their employer? The trouble has been that both have sat complacently and allowed themselves to be advertised by those who do not know—allowed themselves to be shown wrong side up as it were. Does an employee know that if his employer has made money this year that the chances are that it will go into new machinery and equipment next year? Does he know that through some change in the manufacture and design that new machinery purchased this year will be good for nothing but the scrap

heap next year? Does he know that during periods of depressed business his employer is compelled to take work at a price far below what he should simply to give him work and hold the organization together? Does he know that while his employer is eager to pay higher wages, to provide better equipment, and to have more ideal working conditions, he cannot because of the fact of keen competition? He may be willing to pay five or ten dollars a day to his workers, but he finds himself bidding against others who pay $3. oo per day. Does his employees know this fact?

Different concerns have adopted different methods of education. Some have been successful, many have failed. As you are well aware, some employers have entered upon elaborate plans for the betterment of working conditions and the welfare of their men, only to find that their efforts were not appreciated but even ignored and misinterpreted; and where these results have obtained, we believe you will find something was lacking in their method of approach.

You will perhaps recall many paternalistic enterprises that have been started as a solution of the so-called labor problem; but you will also recall that none of these have proved effective, and for the good reason that they were not fundamentally conceived. Any plan that smacks of paternalism can not succeed. It must be a wholehearted effort to get to the bottom of discontent, and this can only be accomplished when the spirit of confidence is secured. The average man is at once more or less suspicious of any attempt to hand him something for which he was not looking.

Many of us are at least somewhat familiar with the early experience of those employers who introduced new methods of production and payment into their factories. We know how they were misunderstood. Some made the mistake of pushing the plans too hard—forcing them upon the men before they grasped the real purpose. Others were wiser and adopted the plan of getting hold of those men who were most intelligent and so instructing them that their influence and proper understanding made it easy to reach the less credulous. And this is where the good judgment of the leaders called to handle men will prove an asset. Every organization should pay particular attention to the selection of their leaders or department heads, for as the leader is, so will be his men. You cannot have an unintelligent department head and expect the men in that department to be up to the standard. Like begets like. We create as we think. If we think disorderly thoughts we have disorderly people and things about us. If the department head is mean, the chances are that he

will have a good percentage of mean men under him. Big, broad-minded men will not be content to work for a department head whom they cannot respect. And this same reasoning applies to the President of the concern, the general manager and superintendent. Men unconsciously gather about them people of their own view point and disposition.

Every employer is anxious to have men about him who can grow—men who are not content with staying on the same job longer than he can be advanced to something higher. This can only be secured through education of a man. There should be a constant movement toward the top where there is a proportionately greater demand. There is much in increasing mental efficiency as well as increasing the ability to turn out so much work of a certain product in a certain time. One of our oversights has been in not teaching men to think, and therefore we have no way of knowing to what extent a man is capable of thinking. We only know that he is performing work that requires a mininum of mentality, but we don't know what his real value might be if given proper instruction. Those of us who have sought to develop the latent powers of workmen know that results of a remarkable standard have been secured.

It is to be regretted that in handling men the chief element has been overlooked—the element of human nature. Men refuse, and they have a right, to be regarded as objects of charity or as parts of a great producing machine. Important as are different systems of present day production, and with all consideration for their industrial value and necessity, all must be built upon well defined principles—or in other words—the science of human relationships; and any system that disregards this, must fail.

The great trouble with employer and employee in the past has been that both have been guilty of doing most everything to keep from getting together. They spent hundreds and thousands of dollars in fighting each other, but seem to have little to spend to find out why they cannot understand each other better.

We may appoint commissions without number to study why these conditions exist, and their investigations may be good; but the real solution will be brought about by individual employer and employee themselves.

It will be brought about only when there is an honest desire to be absolutely fair. When both have realized that their individual success is as much the result of right mental attitude as it is of any system

of economic production, a start will have been made toward the goal of mutuality.

And the means of securing this proper mental attitude are simple, direct, inexpensive and right within every organization where men work together. The best workmen go to the places where best working conditions prevail, and therefore it is important that these places where men work are clean and wholesome. The average workmen is mightily appreciative of consideration in his behalf. He may not show it at the time, but it is in his heart just the same.

Humanity does not differ to any great extent on the average. Men do not want to be paternalized; but they are responsive to kindly consideration. They may not manifest much enthusiasm at the mention of the company for whom they work; but if the leading personality of that company has shown itself to be human—to be interested in the troubles, joys and incidents that go to make up the life of the men who constitute the basis of its existence, there is a response that is really manifest.

An encouraging word from the real boss may mean more—in fact does mean more to some men—than a raise in wages. Highest pay and perfect physical conditions are not necessarily a guarantee against discontent.

Anything that is for the welfare of the employee must be conceived and understood as such. Its purpose must not be disguised, for men do not care to be advertised under the head of improved conditions. The home life of the employee should not be interferred with in any scheme of general betterment unless it is done with the greatest care and only after it has been shown that such action is the only remedy and there has been a desire expressed by the employee to have it done.

There is no reason why any business concern cannot put the question of handling men and their welfare on a business basis and frankly state the business reason for such undertaking.

This is a point some employers have emphasized in all their welfare plans. In fact their employees distinctly understand that anything the company fosters for their benefit, is based upon the belief that it will bring returns in dollars to both.

When employees have learned that capital and labor are interdependent—that both must prosper on the same basis, a good beginning will have been made. They will learn that demagogues and agitators do not fill envelopes, and never will. They will learn that co-operation and not disintegration is the evident need. Men with red blood in

their veins only want an opportunity to help themselves, and any system that overlooks this act, must pay the price of oversight.

At the conclusion of the paper by Mr. Grieves the student body gave rousing cheers led by Mr. Dupre for each one of the speakers, including the presiding officer, the Dean of the Engineering College, and last a sky rocket cheer for Mr. Thompson, President of the University.

PROFESSOR DEMOREST

I would like to ask Mr. Grieves at what point he found the engineering graduate most likely to fall down.

MR. GRIEVES

It has been my very great pleasure to be associated the last eight or ten years with one hundred and fifty to two hundred engineers. We are proud of our engineers and think that they are just about as good as there are. Professor Demorest's question is somewhat embarrassing. I know you are here to get the truth. I would say one thing more than any other that stands in the way or the progress of the average engineering student in leaving school, is that he is inclined to think of work in terms of technical engineering. The engineer is a highly educated fellow, above the average as far as intellect is concerned, but he must not forget there is another side to know. I am glad to know this human congress has been started. I believe it is the beginning of a new area of greater possibilities for the engineering student. I would like to say to the student of engineering when he goes out to take his place in industry, don't remain over the drafting board or even as chief engineer. When a man comes to our employment office the possibilities are there for him to be general superintendent or possibly president of the company. It is up to the man. Men have been employed twenty-five years without much advance, and men who have only been there a few years are at the top, simply because they have laid hold of the opportunities.

QUESTION

I believe one of the great problems of the day is placing the right man in the right place. Mr. Grieves speaks of a man being with the company for twenty-five years; seems to me that man is not in the right place. I think when the man started out if he had taken some interest in the work he would have gradually developed into a greater position. I would like to ask what steps the Jeffrey company has

taken toward placing the right man in the right place. A man comes there with no qualification; how do they know where to place him?

MR. GRIEVES

That is studied very carefully in our employment department. We are not very orthodox in the so-called employment methods. We believe thoroughly in the importance of selection,—but you know as well as I, the proof of the pudding is in the eating. We test the man's ability and in that way he is advanced. A man coming to us for employment is questioned very closely, as to where he worked, why he left, etc., in order to ascertain whether he is coming clean to us, if we feel he is the man for the position he is sent to the foreman. We try to think of every man in the spirit of ourselves, for we too might some day be looking for a job, none of us are immune from that possibility. The department head must be the final judge. He is held responsible; therefore he should have considerable liberty in the selection of men.

We can't tell when a man is going to make good. We don't discharge a man at once, not only for the sake of the man, but because it is tremendously expensive. We try to prevail upon him to stay after once hiring him and try to make a better man of him. We want to do it. That doesn't fit into the statement of the man having been with us for twenty-five years, but we always have those kind of men, sometimes a lack of desire to go ahead, sometimes a lack of ability. I haven't worked out the solution.

FRIDAY AFTERNOON SESSION
OCTOBER, 27

President Thompson, Presiding Officer

The first address on our program this afternoon is by Mr. Towson. From his intimate knowledge of the problem, he will show us that the human factor in industry is a larger and much more comprehensive problem than many have assumed it to be. It is a very great pleasure to hear from a man who is an active member of the Industrial Department of the International Committee of the Y. M. C. A. which has so much to do with the human side of industry in our day. I take pleasure in presenting Mr. Towson.

THE HUMAN FACTOR IN INDUSTRY
THE IMPORTANCE OF THE MAN WHO HANDLES MEN

Charles R. Towson

As I look into the faces of the coming engineers in this audience and remember some of the needs that exist in the realm of industry to which so many of you are going, I am reminded of a text in the Great Book—"Blessed are the Peacemakers". There is need for men who can make peace. I recall no special promise to those who wait for peace but a superlative reward is promised to those who make peace.

Grit in the Wheels

There is need for the two parties in industry getting closer together and understanding each other better. One day this week in an office building in Pittsburgh, I spoke with the head of a great industry regarding a matter concering the welfare of their men. In the course of the discussion he said, "We have just one way of doing things; we determine this for ourselves and nothing else goes". That was an echo from the rapidly disappearing past. That attitude does not make for peace in industry. It is not unlike the attitude of a group of working men(the I. W. W.) I met on the Pacific coast who said, "We are not going to compromise. The present order must be upset. The means of production must be in the hands of the producers and the wealth of the world in the hands of the workers of the world." Both of these

points of view are penalizing industry. We must have more leaders in industry who have the get together spirit and many of them will come from just such gatherings as this where engineering students are led to think on these things.

In this meeting we are breathing the atmosphere of good will. We really seem to be in a religious assembly for the spirit of real religion has been expressed repeatedly by the speakers in their references to mutuality, consideration, co-operation and friendliness.

We are not surprised that there are antagonisms between the employer and employee when we remember how many forces are emphasizing differences rather than agreements. For example we find many of those who occupy chairs in sociology and economics in our universities declaring that "the interest of employer and employee are not and cannot be identical". Others say "these interests may be identical in production but in distribution they are opposed" etc., etc. Far removed from the universities we have leaders of the I. W. W. teaching a similar doctrine but teaching it more violently—nothing in common! antagonism and unrelenting war between labor and capital! Between employer and employee nothing but strife!

Oil on the Bearings

Just as we have those waves of emphasis in the religious life which we call revivals, I feel that we need a great revival of emphasis upon the AGREEMENTS in industry, upon mutuality, good will and co-operation. An illustation of this is furnished in the story told us today by Mr. Hicks of the Colorado Fuel and Iron Company. I am glad to believe that this attitude is becoming more prevalent in industry.

The Young Men's Christian Association is helping to promote this peace basis. We work in the zone of agreements between employers and employees. Some do not understand how we can be related to both. We have been told that we cannot successfully serve the two parties, that we will inevitably become the tool of capital or obey the behest of labor; but we are operating in a hundred different industries in the great cities as well as in the cotton mill villages, coal mines and lumber camps, etc. The employers and employees are co-operating and both are bearing their share of the cost and responsibility of this Y. M. C. A. welfare work which is mutual and constructive.

The reason for this success is found in the new estimate of character values which industrial leaders now have. There is a new appreciation today of the part that the unseen spiritual forces play in efficiency and production.

Let me urge you gentlemen of this engineering school when you get into action in industry to display something of that genius with reference to dealing with human factor that industrial leaders in the past have shown in handling machinery, material and marketing products. Remember that this is a call to a new and mighty Evangel. The mission of the engineer has been described as "relating material forces to human welfare." I urge that your profession shall include relating material aud human forces to human welfare and to remember that the welfare of those who build a bridge or a railroad is as important as the welfare of those who use it. Become engineers of environment, promotors of goodwill, peacemakers in industry!

Value of Knowing Men

One way to do this is to get into contact with working men and boys now while you are undergraduates and learn to understand their point of view, their needs, ambitions and handicaps. This can readily be done. For example, two thousand university men gave time regularly last year to teaching foreign born working men the English language and citizenship. They did this not only to help the foreigners and thus render a fine social, religious service but also to enlarge their own knowledge of men and thereby become better equipped for managerial positions.

These coming engineers will not make those mistakes that some employers are making because of a lack of this knowledge. For example, a superintendent of a department of a large industry was asked what was the point at which the employees in his plant fell short. His answer was, "They don't need any education for the work is automatic and quickly learned. Neither does their physical condition make much difference for the work is easy; but I wish they were more dependable and showed a better spirit about their work." That superintendent does not understand men. He has not realized that men were made to develop in body, mind and spirit; if the body and the mind are sub-standard, the moral and spiritual standard cannot be normal. He does not know that attention must be given to the *allaround* man. That superintendent expects men to maintain a high standard morally while neglecting the mind and body, and this is an impossibility.

Allround Welfare

This allround welfare of the workers is the practical concern of every employer. The physical welfare of the worker should be of great concern, for in no single industry can it be said of the workers

"they are physically fit." The workers' lack of intelligence and training causes employers sleepless nights, for regardless of whose fault it is they are far from a hundred per cent. But the greatest loss comes to industry when the *spirit* is wrong. The sub-standard body costs industry its thousands; intelligence below par costs its tens of thousands; but what are these compared with the loss that comes when the spirit of good will is lacking! Then comes careless neglect; then "withholding efficiency" and other forms of sabotage; then open strife; then destruction.

NEW STANDARD OF VALUES

This is the day for a new estimate of spiritual values in production. The greatest forces in industry are like the electric current—unseen. *Integrity*, for example, cannot be reduced to a formula but it is a real financial factor. It will take a remarkable stopwatch or piecework system to offset the lack of integrity on the part of employees whether that lack be shown in dishonesty or in careless indifference. Intelligence cannot be put under the microscope but the lack of it is bound to show in the dividend column. Some really see this. Others having eyes see not. The dollar and cent value of that intangible thing we call stability is and always has been great. An operator said recently that fifty per cent of his total cost of operation is in changing labor. One mill manager told me that in one year he hired ninety-six men to keep twelve positions filled. What a penalty industry pays in its "turnover"!

But the greatest of all these unseen forces is the *goodwill* of the worker. Suppose that the workers may be induced to stay on the job. Assume that there will be few changes. What will it amount to if the *spirit* of the workers is not right? THE SPIRIT OF THE WORKERS IS INDUSTRY'S GREATEST ASSET—OR LIABILITY. This fact cannot be stressed too much and one of the greatest factors in begetting the right spirit is *the man who handles men*. Wages, hours and working conditions do not control the attitudes of men. While very important, high wages, short hours and good conditions do not guarantee industrial peace. Goodwill is a human attribute which cannot be begotten of material forces; Human contacts alone create it.

Friendliness between employer and employee is not a substitute for wages, hours or conditions but without it there is no safety. If the man next to the men is a friendly man and the workers have recognition as men, there will be prospects of peace. If he is there simply for what he can get out of the workers, their goodwill is impossible and industrial war is a certainty.

THE Y.M.C.A. IN INDUSTRY

The Young Men's Christian Association is offering its service in two definite ways. Wherever established in relation to industry, whether in factory districts or mining villages, mill towns or camps—it helps to develop the allround man—body, mind and spirit. It affords a place where men get together in an atmosphere that makes for peace and goodwill. It brings to the surface the best there is in men and provides through the Secretary, a leader who is a mutual friend of employer and employee and who multiplies friendly contacts. A hundred different industries, from the United States Steel corporation down to a lumber company employing less than one hundred men, have erected Y.M.C.A. buildings and jointly with their employees maintained a local Young Men's Christian Association with a trained secretary.

The second special service the Association is rendering is in the Industrial Service Movement which is illustrated in part in this Congress. This movement enlists engineering students to know the industrial problems of the day; to know something of the Plans that improve industrial conditions and relationship and to know industrial workers through personal contacts in some form of personal service. By this experience acquired as undergraduates hundreds of coming engineers who are to handle men will be better equipped to deal with the human factor in industry. They will understand the needs of the workers and their point of view. They will know how to beget that friendliness and goodwill which is the basis of industrial peace. They will become industrial peacemakers.

PRESIDENT THOMPSON

I think we all recognize the word engineer as a word of large meaning. I used to think of the engineer as a civil engineer, a mechanical engineer or an electrical engineer. I don't now. I think we all are seeing the human factor in the problem of engineering. It is a factor which we must learn to love and admire.

Now in following our program we are going to introduce a new form of discussion, and call upon Miss McCorkle to offer some remarks.

MISS MCCORKLE

If I had the power of Washington Irving, I believe I would like to turn seven million wage earning positions into a sleep like Rip Van Winkle's just to understand what we mean by industry and the great world about which we have been talking.

The Y. W. C. A. is coming into vital relationship with all industrial activity involving women and girls. When we speak of a woman's job in the factory, we forget that is only a part of her job. The man comes home after his day's work is done to rest. The woman comes home to prepare the meals, attend to the children, clean the house, and mend the garments, so her day's job is never done. Then we must realize the fact that when the girl goes out in industry she loses much of her individualistic life. You as men have been telling us in unity there is strength,—in group work there is power. Women in the home are just beginning to work together in groups. Women's clubs have been organized and there they have learned that they may think and develop their powers. Girls are workers from early morn until late at night aud they must have the same chance of expression, the same opportunity of getting together as the men have. The Y. W. C. A. has been the means of organizing a federation of industrial clubs for young women. It is through the club that they find self expression. We have a committee come together in the summer for council, just like students. These clubs meet, the Y. W. C. A. being the center, and are federated under one council. I can't tell you what development this has caused in the homes with which I have come in touch. Four years ago in my district we had six hundred girls, now we have twelve federations and thirty-five hundred girls in the federations. I think you would be interested in seeing women who never spoke before a group,—you know how hard it is to get up on a floor like this, and to get the girls to a place where they can express themselves—take part in intelligent discussion. It certainly gives the girl an opportunity to develop, brings to her something of what the college does to the young man.

In many industrial plants the managers see to it that the girls are not subjected to annoyance from unscrupulous foremen and others. But often the conditions and influences surrounding the girl workers are bad and they need protection, so the Y. W. C. A. is seeing to it that in such circumstances the girls are protected. The girl is entitled to fair play and when this is given her the nearer we are getting to the spirit of sisterhood and brotherhood which we need.

PRESIDENT THOMPSON

I am sure we are glad to bring to mind for just a moment this subject as Miss McCorkle has presented it. Thousands of women in American industry are presenting a problem quite as serious as that

presented by the men and in which as much engineering skill will be needed as with the men.

Before introducing the next speaker I beg to say I knew him a long time when I was living in Miami as president of the University and I was associated with him in clubs in Cincinnati. I remember him in Sunday School work, a quarter of a century ago. I am pleased to present to you Mr. Shuey, graduate of Otterbein University, a long time resident of Dayton, and an old friend, who will speak to you on, "Human Engineering in Welfare Work".

HUMAN ENGINEERING AND WELFARE WORK

EDWIN L. SHUEY

It is a pleasure to leave for a day the details of a busy office and join with you in the study of some of those questions that are among the most important of our day.

This occasion is in marked contrast with the student conditions of a generation ago when the curriculum was narrow and the opportunities of learning practical conditions beyond the college confines were far less than now.

When the theme for this discussion was indicated it was suggested that I speak of some practical experiences rather than of theories. In accord with this suggestion what I shall say will be rather personal, but I hope practical.

About the time—some twenty years ago—referred to by President Thompson, a group of business men in one of our Ohio cities began the discussion of the perplexing problem of the relations of employers and employees. The subject was indefinite for until about that time most of this country had been occupied with the questions of machinery rather than of men. It is probably within the truth to say that then there was no "human problem" in manfacturing—it was all machines. The question was not—"How may we get better men?", but "How find better machines". We had to learn the truth that the finer the machine, the more ability required to use it, and the more important truth that men should not be used to do the things that machines can do.

During a visit to a great Irish Paper Mill where women were making envelopes by hand at from 75¢ to $1.25 per week, the Superintendent was asked for an explanation of this fact. His answer was "These machines are cheaper than the others". Nor was this an isolated example of the indifference to human life in manufacturing Life was cheap—machines expensive.

It was about this time that the speaker undertook the organization in a large factory of what would now be called a Welfare Department. The work was pioneer work just as much as that which was done by the Company in manufacturing was pioneer effort. There was little to guide us in the way of precedent and only right intentions to tell what ought to be done. It was realized that the employees were giving probably 60% of their effort, not so much because of indifference as because of lack of knowledge and unfavorable conditions. The problem was to secure as nearly as possible 100% of efficiency and effort, and retain the good will, health and ability of the employees. In the years that have intervened since this work was begun, I have learned something of what may be done in both large and small factories, in suburban and city plants.

Through these years the important questions in manufacturing have changed. Today the human problem is the primary one, the machine is secondary; in the years to come this element will be even more prominent. He will be most successful in his own manufacturing and in his relations among men who most fully recognizes the ambitions and abilities of the men who do his work.

What is "Welfare Work"—the term which we hear so often in these days and which has such a varied meaning? In its inception it was the expression on the part of employers of their sense of responsibility, not only for working conditions of employees, but also for their surroundings, home life, education and civic relations. When men began to study these problems they realized that quality and quantity of output depend almost as much upon surroundings during leisure hours as upon factory conditions during the working day. Naturally therefore Welfare Work deals with questions of conditions of working, conditions of living, conditions of education and civic relations.

It must be realized that the motive of those who have undertaken Welfare Work is generally unselfish, with the thought of gain to others more than to themselves. In practice it is the recognition of the mutual responsibility for all working conditions. It was Mr. Lever of Port Sunlight who explained the beginning of his great enterprise by saying that he preferred to spend his money in building a town and joining with his employees in developing life, rather than in sports, yachts and recreation. Another great employer became interested in the life of the women employed and soon found his interests widening to all employees and then to their families.

In Europe some great enterprises had long been recognized and had proved successful. Port Sunlight, Cadbury, and similar efforts are

very well known, but do not meet American conditions or American inclinations and independent thinking. In this country the individuality of men must be recognized and their participation in projects must be secured.

When these plans were first developed there were many enthusiasts who thought that a solution of the relations of employer and employees had been found and that difficulties were past. It was soon found, however, that this is only a step in the solution—an important contribution to the great problem of human life and industrial relation. Experience has emphasized that no system accomplishes all, for the human element must always enter into consideration, and personal characteristics are more and more important as standards of life and work change.

Briefly stated as practiced generally in this country, welfare work has to do with comfortable factory working conditions—light, heat, fresh air, cleanliness, baths and toilets, lockers provided so that employees may change their clothing if desired, proper conditions for eating when men and women must eat about the factory; attractive surroundings for factory buildings and grounds; convenient methods of getting to and returning from work; relief and insurance associations for mutual assistance; proper rest and recreation opportunities; factory clubs and organizations having for their object a better living and better recreation; and the many other things that have to do with conditions immediately connected with working life.

Beyond the factory in many places Welfare Work has to do with neighborhood conditions, good homes, economical living, attractive yards and streets; good schools adapted to the neighborhood in which they are located; healthful occupations for boys and girls as well as men and women. Gradually such influences widen until the entire community is influenced and changed. This extension of influence into the home and living conditions of working people is most natural as experience has repeatedly shown. The men and women who are accustomed to clean and cheerful working conditions for eight or ten hours a day, will not be satisfied with slovenliness at home or in the neighborhood when the working day is over. If there is a good bath at the factory the man wants one at home, and soon the type of house and standard of living is changed.

Daytonians do not hesitate to acknowledge the influence of Mr. John H. Patterson in bringing about the beauties of our city as we have them today, and the unusually high character of living condi-

tions. The beginnings of these changes were in the early Welfare Work of his great factory.

Nor is the influence entirely institutional and social—it is as truly personal. With high standards of character the ideas of young men and young women rapidly change for the better. Boys and girls are kept at school longer where employment is desirable and where employers insist upon better training. In the neighborhood of the National Cash Register Company in our city, many boys and girls went back to school when they found that the factory would not employ any one under eighteen, and would insist on school training. It becomes a question whether our great manufacturing establishments are meeting their responsibilities if they do not become an important factor in the education of the youth of the community in which they are placed through such influence as this.

It is true that many manufacturers cannot undertake all the things included in so-called Welfare Work, because of location or crowded surroundings, but all can give fairly clean conditions and those things that assure comfort in working. Proper physical surroundings are the first essential to contentment and enthusiasm in work, and to successful Welfare Work of any kind.

A few principles are essential. May I suggest two or three things briefly, not because they are new, but because they are fundamental?

I. There must be recognition of the manhood of the man and womanhood of the woman. Employers must fully realize that their employees are able to think, to feel, to judge; must acknowledge their right to "life, liberty and the pursuit of happiness" at home and in civic life; must encourage their ambitions for their children and for honorable social recognition. Among American workmen this is an absolutely essential relation. As the foreigners become Americans these things become prominent in their own thoughts. The day is past for the expression "I do not want our people to learn anything. I want them to do what I tell them to do."

One only needs to watch casually the change that comes in men and women in factories where encouragement is given to best living. Of course they will need higher wages, but the return they give will be in far greater proportion.

II. The initiative for many things done in Welfare Work must come from the employees rather than the employers. Welfare Work is not always understood because so much of it has come from the kindness of heart of some employer whose inclination is to start things at

the top and carry them down. The unfortunate suspicion comes too frequently under such circumstances that the employer has some ulterior motive, and he is compelled therefore to overcome prejudice which would be entirely absent if some of the things were permitted to start at the bottom instead of the top. In short, give to the employees the opportunity for initiative and they will very quickly respond with improved effect.

Experience indicates that employees will ask less than the employer would grant, and that they would be more careful than the employer himself in development of the very work he wants done. I recall very clearly the fact that in one factory where prizes were offered for suggestions, the entire theme was dropped after a few years because a group of the most loyal employees themselves suggested that it should be discontinued because the employers were not getting value for the money which was spent. In factories where relief associations are in existence, it has been found that the committees of employees are much more careful of all details than the employers themselves would be.

In short, men and women who must much of their time be occupied doing the things that are given them to do, are encouraged when the opportunity comes to "start things" themselves. When encouraged they are likely to start the proper things.

III. Proper limitations of what is undertaken for and with employees, especially after working hours, is important for successful effort. Men and women regard their leisure hours as their own, and an effort to do too much for them is likely to lead to objections. On the other hand the proper encouragement to the right use of their time and the right conditions of life is bound to receive enthusiastic response.

Neighborhood Improvement Associations, which are so often the outgrowth of some local Welfare Work, are sure to have widest results when members themselves are permitted to determine how extensive the work is to be. Tactful evidence of lack of preparation for higher positions assures proper training schools in many communities. Appeals to social instinct and community spirit often lead to all round personal improvement. Almost without realizing it whole neighborhoods are frequently changed by simple encouragement and tact.

IV. No "Welfare Features" will maintain business in any factory and community if factory working conditions are not as good as is possible to make them, and if wages are not maintained to at least the current standard of the community.

"What more than wages" is the practical question in all these Welfare efforts. It is the plus that makes possible the best human relations and the most successful Welfare Work.

The ideal relationship is that of personal interest and knowledge of men and their surroundings, their families and their ambitions. It is here that the smaller factories have the advantage over the larger, in that it is possible to have a closer personal relationship.

The tendency to depend upon organization, law and regulation to solve our problems when nearly every difference in relationships arises from some personal interest, emphasizes the importance of the human element in all factory plans. Much may be accomplished by legislation, though not as much as often thought. Most will be accomplished by mutual confidence and respect. It is in these directions that the Young Men's Christian Association, to which reference has been made frequently today, is particularly valuable. It has proved to be a broad medium for arousing human interest and encouraging mutual dependence. "Bear ye one another's burdens" is the essential principle of Welfare Work and of all that is connected with it. The responsibility for the things suggested by the term will lie very largely with the engineers and the young men who are to be the leaders in manufacturing in the coming generation.

At the end of Mr. Shuey's address a fifteen minutes recess gave opportunity to the audience to move about and discuss the previous speeches.

PRESIDENT THOMPSON

It will now be to our pleasure and profit to hear our subject discussed by a man who will present it from an entirely different point of view. It is very fortunate that we can have this many sided discussion of human engineering. I am glad to introduce Mr. John A. Voll, President of the Ohio State Federation of Labor.

HUMAN ENGINEERING FROM THE VIEW POINT OF A WAGE EARNER

By John A. Voll

Human engineering, the subject of this congress, is so broad in its scope and wide in field that there seems to be no beginning or no ending. Yet, when we view the narrow confines of its practical application in this day and age of civilization, it is to wonder at the lack of applied Christianity in our own country and in the world that without doubt has resulted largely in the callousness of man's interest in man, and has allowed material interests and material rights to overcome and place in a secondary position, human interests and human rights.

Of this the great Pope Leo 13th, from a passage in his encyclical letter, May 15, 1891, on the condition of the working classes says:

> "Hence by degrees it has come to pass that working men have been surrendered, all isolated and helpless, to the hard-heartedness of employers and the greed of unchecked competition. The mischief has been increased by rapacious usury, which, although more than once condemmed by the church, is nevertheless, under a different guise, but with the like injustice, still practiced by covetous and grasping men. To this must be added the custom of working by contract and the concentration of so many branches of trade in the hands of a few individuals: So that a small number of very rich men have been able to lay upon the teeming masses of the laboring poor, a yoke little better than slavery itself."

This statement of Pope Leo is borne out by the committee of Federal Churches of Christ (comprising some eighteen Protestant denominations in our country) in their investigation of the conditions at South Bethlehem, Pa., and what caused the strike at the Bethlehem Steel Plant in 1910.

The strike was caused by three machinists protesting against their fellow workers being forced to work on Sunday. The committee found there was no organized men in the plant and that more than half of the nine thousand men employed, were compelled work seven days a week, twelve hours a day, and that everytime the day and night shift turned about, these seven day workers were required to put in a long turn of twenty-four hours of consecutive labor.

Of wages the committee says, twenty-one men out of the 9,184 employed, earned 60¢ an hour. This would be $7.20 for a twelve hour day. But on the other hand, sixty-one percent earned less than

18¢ an hour, or $2.16 for a twelve hour day and nineteen percent earned less than 14¢ an hour, or less than $1.68 for a twelve hour day. The committee further says, "this is a wage scale that leaves no option to the common laborers but the boarding boss method of living with many men to a room." When a man has a family with him, they take in lodgers or the woman goes to work. It is reported that immigrant parents send their little children back to the old country to be reared while the mother goes to work. On such wage basis, American standards are impossible. The January 1910 pay roll at Bethlehem showed according to the Bureau of labors, large numbers of laborers working for 12½¢ an hour, twelve hours a day, seven days a week. This report was signed by Charles Stelzle, Josiah Stong, Paul U. Kellogg. Hence, it must be evident to all the great need for human engineering.

Illustrative of this, is an expression from the lips of a man in my presence not more than a week ago, that when forced to accept a job that compelled him to work twelve hours a day, he did not do two good hours work knowing that it was impossible for him to keep up his standard of efficiency and hold out. It resulted as he stated in his watching the foreman so that he could be busy when that individual came his way. Of this he was ashamed and in further statement said, had his hours been reasonable, he could have done justice to both himself and his employer wheras he did justice to neither.

"Mankind," says Emerson, "is as lazy as it dares be". And Sydney and Beatrice Webb, authors of "Industrial Democracy" add, "and so long as an employer can meet the pressure of the wholesale trader or of foreign competition by nibbling at wages, or cribbing time, he is not likely to undertake the intolerable toil of thought that would be required to discover a genuine improvement in the productive process, or even to introduce improvements that have already been invented.

This position and unprogressive spirit, means the holding on to long hours and low wages, both of which are productive of inefficiency and sub-normal production.

Human engineering largely involves captains of industry, men who know how to lower the cost of the product without lowering wages or nibbling at time. Such for instance, as Mr. Henry Ford, who raises wages and shortens hours, yet continually lowers the cost of the article he produces to the buyer.

The engineer, no matter of what description, to be successful in his work and in getting the best results from his plans or planning,

must combine the human factor in whatever he may set out to accomplish.

If this is not done, his work will be a partial failure in that he will not secure the best results though the project under his supervision be brought to a successful termination.

We have in our time the most vivid illustration of this fact when the French under DeLesseps attempted to build the canal across the Isthmus of Panama. Had the human element been considered as the greatest factor in the completion of the plans and provision made for the health and welfare of men, there would have been a different story to tell today relative to the now completed canal. Men died by the thousands under the French attempt at construction and those who lived and toiled could give but little of the effort they were capable of, had normal instead of sub-normal conditions prevailed. Hence, the failure of the project.

Later we see our own country take up this gigantic problem of engineering and what do we behold. A combination of civil and human engineering.

Colonel Gorgas, probably the greatest living expert on sanitation in the world today, immediately set to work to make the canal zone habitable for human beings without undue risk of life or health and in this he was eminently successful. Instead of men dying by the thousands, we found a healthy lot of well paid, contented men on the completion of this project.

But all did not go smooth from the beginning, owing to the absence of democracy as between the engineer and the wage earners, which to an extent, nullified the great work of Colonel Gorgas in that the best results could not be obtained even though health conditions were good.

After the resignation of Mr. Theodore Shonts, and the appointment of Colonel Goethals, as cheif engineer, matters in the canal zone assumed a different aspect. New life was injected, bickerings, dissatisfaction and dissention, were immediately reduced to a minimum, with the result that the dirt began to fly and the work performed was the wonder of the world, and why? Colonel Goethals introduced democracy into the project. I am told by men who worked on the canal that every Sunday morning at ten o'clock, those who had any greivance, could place it before Colonel Goethals, ranging from committees of the highest skilled wage earners, to the humblest laborer on the work, be he white or black, and all were assured justice would be accorded them

The effect of this was marvelous. No under engineer or foreman of any description, could in any manner impose upon the men unjustly, without it coming to the knowledge of the chief engineer who combined human engineering with his work and the result is, the successful completion of one of the grestest engineering feats in the world's history, in less time than had been calculated and with satisfaction to the country and to all who had a part and without scandal of any notice.

This feat established beyond doubt, that a combination of human engineering and democracy in any project or enterprise whether it be public or private, will bring the best out that there is in men. These are economies that can be measured in large profits and humane propositions that prolong life, help to maintain health, making at the same time great strides for peace and contentment as between capital and labor, vivifies love of country and patroitism that naturally burns in every good citizen's breast, and has a great civilizing influence upon those who come to our country from foreign shores.

On the other hand we see the results of the absence of human engineering and democracy in industry, in the strike and riot that occurred at East Youngstown last January, when upon investigation, we found the strikers were composed mostly of foreigners of several different nationalites that for years had been exploited inside and outside the mill, that they were compelled to work twelve hours a day, seven days a week and in several instances, as high as four beds were found in one room. Out of a population of ten thousand,there were 451 voters and 1,100 children in the schools, nine of which were in the High School, 20 in the eighth grade, ten in the seventh, thirty in the six, fifty-three in the fifth, 152 in the fourth and 825 in the first, second and third. We also found that the Company had objected to night school for the adults. This tells the story of what caused the rioting in East Youngstown, when the men struck,because of no human engineering or liberty of expression and action relative to the inhuman conditions imposed upon them.

Contrast the difference between the Panama Canal relations and the relations of East Youngstown. Then draw your own conclusions as to whether humanizing influences are needed and necessary in engineering, and if combined with democracy, it does not stand out as a beacon light of great power and magnitude for good, as compared to the degrading influences for bad where they are absent or ignored.

In the field of human engineering through legislation, some progress has been made, but instead of applying the full worth of the engineering, for the uplift and alleviation of the human family, efforts

are continually made to checkmate or nullify the good accomplished through statutory law. Profits, the dollar, is the stumbling block to human welfare and human progress and it is true as Justice Brandeis has said, "The only dollar worth while, is the properly distributed dollar. Any other kind is not worth the consequence it entails. It leaves desolation behind it and corrupts even those who garner it in. Huge profits mean a loss to the community and its citizenship. They cannot be made except at the sacrifice of what is worth more than mere money."

This truism is evidenced by the fact, that out of 339 prosecutions for violation of labor laws in our state, the past few years, 320 were found guilty, over half of which had their fines remitted or suspended. The greatest offender in this line, was Judge Armstrong of Cincinnati. The Oscamp Bolting Company of that city, was prosecuted, found guilty and fined thirty times, for working women more than ten hours a day. In each instance, Judge Armstrong either remitted or suspended the fine. The Snyder Preserving Company of the same city, was prosecuted, found guilty and fined eighteen times for the same offense. In each instance, Judge Armstrong, suspended or remitted the fine. This is human engineering set aside, practically nullified through inhuman engineering by our judges and courts, the majority of whose flagrant partiality for upholding property rights, as against human rights, are too well known to need further comment.

That great piece of human engineering, the Workman's Compensation Law, which as a state monopoly, coming under the police powers of the state, is a combination of humane and economic legislation, highly benificial to the employer and employee alike, is being attacked and jeopardized through such insatiable greed as the making of profits out of the injuries and deaths of human beings in industry and if successful will largely destroy the humane and economy features of the law.

Another great piece of human engineering, the mothers' pension law, is almost a dead letter in those counties that have no well directed organizations to see that it is put into execution.

Just so long as office seekers and unscrupulous politicians cater to the interests, dollars, for campaign expenses and funds, just so long will human engineering through legislation be set aside or be partly nullified.

Human engineering in the industrial field, has as yet hardly scratched the surface. When we take into consideration that about 250,000 wage earners lose their lives each year in the United States,

and from causes that can be prevented and as Dr. E. F. McCampbell had pointed out, while Secretary of the State Board of Health, that nearly every one of the 36,923 persons that died of tuberculosis in 1909, ought to be living today, it is apparent that there is a wide field for human engineering, when as he says "dust, dampness, darkness, devitalized air, food, fatigue, inactivity, unsafe temperatures, avoidable poisons and infections"— one or more of these, paved the way for "Died of consumption".

In 1891 the organization of which I have the honor of being a member, established a death benefit department, since which time every death and its cause has been recorded. The approximate membership is about 8,000, varying at times increasing and decreasing from various causes. The total number of deaths from September 1st, 1891, to September 1st 1915, was 1,739. Of this number, 553 died of tuberculosis, the average age being 35 years and 9 months and 32% of the total number of deaths. These figures pertain to tubercular disease only and do not include such as pneumonia and hemorrhages of which there were a great many. I take this opportunity to say without fear of contradiction that, at the least calculation, fully one half of these deaths could have been prevented had the methods of work been normal, if some education had been imparted in industrial hygiene and if the conditions surrounding employment had been of such a standard as not to force the workman to constantly risk his life through exposure and other kindred evils which develop tuberculosis.

Human engineering does not consist only of making safe and sanitary places to work in and the eradication of disease; it also means engineering to pay such wages and establish such hours of work as will keep the mind and body healthy, through which as Colonel Gorgas has said, "Life can be prolonged about thirteen years". What an economic feat, what an asset to society, when through an enlightened civilization, these conditions can be firmly established.

Human engineering in the industrial field relative to collective bargaining, has made some progress but its scope is as yet greatly circumscribed, by the position and attitude of those referred to by Pope Leo and the committee from the Federal Council of the Churches of Christ and confirmed by the report of the three employers on the Industrial Relation Commission. Human engineering unless combined with true democracy in industry, is and always will be a failure. We might make palaces out of the work shops, the mills and the mines and in addition promulgate and install systems of charity, welfare work and co-operation on a dividend sharing basis, yet the work would

be a failure, because the human race in working out its own civilization, its own destiny will neither submit to dictation or be placed in a position of some form of dependency, proscribed and administered without having full and free expression on the propositions submitted or advanced with the right to accept or reject, backed with as much power through organization as is represented by wealth and great strength of bought intellect on the other side. Human engineering, I would say, is an extraordinary study in psychology. It represents the hopes, the aims, the ambitions, yes, the very life of the people and its manner of direction is today vital to great numbers of them in employment as wage earners. The mind can be either dulled or quickened, as the human being is susceptible to depression or elevation in spirit in accordance with treatment, surroundings, enviornment, prohibition of the exercise or non-exercise of lawful and natural rights and as the engineer provides for the exercise, or non-exercise of these human elements in his plans, will he be successful, a failure or a partial failure.

The man who has planned an evening with his family, the man fatigued at the end of his day's work, the man who has planned some social recreation, or who made arrangements to look after some little business affair, or who is worried because of sickness in his family, who is told a few minutes before quitting time, that he will be required to continue with his labor for two or three hours longer, the man that has planned a day's outing, and who has given plenty of notice of his intentions, whose hopes are high, whose anticipations for the time, rejuvenate a spirit of life that has been lying dormant, who is held off to the last day or hour, to be then told that he can or cannot get leave off, has had his hopes, his anticipations shattered and the outing is a failure, all because some underforeman, exercises his petty power and authority for the purpose of being kowtowed to, or on account of the fear from higher up that profits might be disturbed by a hairs breadth, the greed of which kills the man's spirit, and subjects him to the conditions enumerated which he must accept in silence and without protest and places him in a position not unlike the ox, in that he must be driven to give service.

If the greed for profit, the amassing of immense wealth, is to continue as a deterrent and a detriment to the wage earner, then it is high time for the good of all, rich and poor alike, that human engineering step in and adjust the flagrant inequalities through a more rightful distribution of wealth.

Humanity cannot and must not, be measured from the standpoint of profit. It must be measured by the soul and the God given rights

which are known as natural rights, to protect and save that soul and whoever interferes with this measurement, through the making of profits or unchecked competition, not only deprives man of his natural rights but is sowing the seed of state dissolution in that such unjust, unrightful exercise of sharp manipulation, power and authority, destroys patriotism and love of country. This is largely borne out in the report of Basil Manly to the Industrial Relation Commission wherein he says:

"The ordinary man whether employer or worker, has relatively little contact with the government. If he and his family are well fed, well housed, well clothed and if he can pay for the education of his children, he can exist under an autocratic monarchy with little concern until some critical situation develops in which his liberty is interfered with or until he is deprived of life or property by the overwhelming power of his tyrannical ruler. But his industrial relations determine every day what he and his family shall eat, what they shall wear, how many hours of his life he shall labor and in what surroundings. Under certain conditions where his employer owns the community in which he lives, the education of his children, the character and prices of his food, clothing and house, his own actions, speech and opinion, and in some cases even his religon, is controlled and in so far as the interests of the employer make it desirable for him to exercise such control. Such conditions are establishedand maintained, not only through the dictation of all working conditions by the employer, but by his usurpation or control of the functions of political government in such communities."

No man working under the conditions of even a slight form of involuntary servitude, such for instance, as his complete economic control backed up by the infamous black list can have the proper spirit of patriotism and proper love of country nor is it within man's nature, to give the best there is in him, under such conditions.

In the field of unemployment the work of the human engineer has been sadly neglected. We saw thousand and thousands of men out of employment in 1908 and 1909 and 1913 and 1914 and in the nineties, we saw armies of unemployed marching on to Washington. The most that has been done up to the present time for relief of this unwarranted condition, is a few spasmodic efforts in spots to give relief through some sort of charity or welfare work and some little public improvement. Nelson Harding produced a cartoon in the Brooklyn Eagle, titled,—"Cold Comfort" in which a fairly well dressed man with "unemployed" written upon his back, is standing shivering in the cold, reading the statistics of unemployment, how many men as a whole were out of employment, and the number of each different craft or calling. The cartoon is typical of the action that so far has been taken to eliminate this great evil.

When through human engineering, the hours of labor can be reduced in conformity with the wealth produced, and being produced, in our country, and when for the purpose of meeting a crisis, a division of time has been worked out, then the cartoon of Richard Harding depicted with so much realism will be but a fading memory of the past and the wage-earner will not be a dependent but will retain his independence, a vital necessity for a viril citzenship.

In the effort now being made in some instances, through physical examination to minimize sickness, prolong life and prevent industrial accident, human engineering has a great part to play, but unless pressure and education is brought to bear to force and to show, that human welfare and human interests, must take precedence over material interests and individual and corporate greed, the effort will be a failure, in that it will rebound to the detriment of the human family instead of its benefit and especially does this apply to the wage earner in that it will resolve itself into a survival of the fittest, in which case the problems of unemployment and the citizen's dependence will be greatly increased.

Hence in conclusion, it might be well for all forces in all occupations and walks of life, to take up and emulate largely the methods of what the writer believes to be the greatest human engineer the world has ever known or ever will know,—the good mother of a family. Her tact, diplomacy, forebearance, unselfishness, impartiality, sacrifice, love, cheerfulness, methods of reward and discipline, are virtues, which the executive, the judge, the legislator, the engineer, the minister, the professor, the captain of industry and his subordinates, the labor leader and all who have any functions to perform pertaining to human engineering, can well study and copy after, for hers is a combination of thought and action that brings to the surface all that is worth while in us without deflecting or destroying the bond of unity that of course, naturally exists (and which to a degree, should exist in the brotherhood and fellowship of man), and without overburdening our minds with fear and our bodies with physical waste.

Mr. Towson.

I commend your interest and attention to the next speaker, who is the founder of the Industrial service movement; which movement has affected the colleges and universities of the country, by equipping them better to understand the needs of the working men and to have that human sympathy which is necessary to successfully deal with men. Professor Joseph W. Roe.

THE COLLEGE MAN AND HUMAN ENGINEERING

PROFESSOR JOSEPH W. ROE, Yale University

I am glad to come eight hundred miles to have some part in this Congress, for in calling it this University is taking a conspicuous part in one of the great movements of our day, and I hope for a wide recognition of its splendid leadership.

I want to take up the college man and the human relationships he will have later with his fellow workmen. Before answering some of the questions which have been raised here it is wise to go back for a moment.

Certain ages are clearly marked in the world's history. The age of machinery came in with the invention of the steam engine, which gave us power, the great textile inventions, machine tools with which machinery could be made, and a rapid succession of other inventions which have profoundly affected living conditions all over the world. When these were let loose upon society they revolutionized industry in a single generation, brought about the great growth of modern cities and led to labor conditions which are almost unthinkable today, with child labor in its worst forms, overcrowding, unhealthful working conditions, long hours and starvation wages. This transformation is known as The Industrial Revolution and its greatest force was felt in England about one hundred years ago. After a period as tragic if not as dramatic as the French Revolution, partly through the growth of a social conscience, partly through factory legislation, partly through the rise of labor unions, conditions began to improve, and today they are better than before the iudustrial revolution came.

The industrial revolution has this clear lesson for us;—machinery *makes possible* a high state of mental and moral development of the whole people, *but by no means insures it.* The spirit with which machinery is brought to bear upon society is going to determine its effect.

This generation finds a new change taking place, the rapid development of the art of industrial management. The engineer will take a vital part in this for he is more and more becoming the head of large industrial enterprises. College trained engineers, from education and training, are fearless analyzers of facts, willing to "scrap" the obsolete, and men of constructive action; the type of man needed in the management of affairs.

More and more they are coming into industrial as well as technical leadership in all forms of manufacture, transportation, the telephone, the telegraph, and mining operations and other activities which together represent over 37% of the workers in the United States. Agriculture represents about 33% and all other forms of livelihood the remaining 30%. The largest body of workers are, therefore, under the direct influence of engineer. He will be the key man in the next generation.

His position is one of unique influence for he stands between capital and labor,in direct personal contact with both, and is the man who knows most intimately what both need. All that "gets across" from owners to workmen must pass through the manager and he may be the weak link in the chain. There have been long and bitter strikes in plants where the men at the top have had only a spirit of fairness and goodwill, but somewhere down the line some superintendent, out for a record, has crowded human nature for more than it would stand, and set off the explosion.

On the other hand we find factories operating on the old piece work basis, with old fashioned methods, at the old working hours, where there is no trouble whatever. Year after year the owners and men work together in a spirit of good will. Somewhere in such an organization will always be found some personality which permeates down until it reaches the last man, some man with a big human soul, a practical altruist who knows and recognizes the workmen and meets their needs fairly and wisely. Such men are worth their weight in gold, and can produce these results under almost any system.

A new element, however, has come into the management of industry. Heretofore attention has been directed chiefly towards the machine. Now it is being turned toward the man who runs the machine. The question is no longer solely the efficiency of the machine, but the efficiency of the man as well. This has opened up the possibility of further and very great economies in production. But unless we look out we may run into some of the troubles of the industrial revolution. It makes little difference whether the increase in productiveness comes through the introduction of machinery or through the increased effectiveness of the workmen. The economic effect is the same. We are not going to have so hard a time as they did a hundred years ago. The possible increases in production are not so great. Labor now has means of defense and today there is a social conscience. But, while the problem is not so acute, it is much the same, differing from the industrial revolution in scale rather than in kind.

The efficiency with which Efficiency itself is applied will depend upon the spirit of fairness and equity with which the possible gains are apportioned between the owners and the workmen whose co-operation makes the gains possible. This equitable apportionment is no simple matter. Everybody agrees that reasonable working hours and fair wages are best for all concerned, but just what constitutes reasonable working hours and fair wages is far from agreed upon. If all concerned can get together in mutual respect and good will it is perfectly possible ultimately to work out the situation to the permanent benefit of all.

The brunt of this problem is going to fall upon the managers of the next generation, and it is the work of the colleges to prepare their men as far as possible to meet this situation. Economics and social science are good, but the fundamental need is a *knowledge of men.* Unfortunately there is no text book on human nature and the only way to learn it is by direct contact. A way, however, which provided this contact has been worked out successfully and is now in operation in more than 150 colleges in this country. Through Industrial Service Work a young man, still in college, can take up work which will bring him into touch with workmen which will enable him to know something of how they think and live and will put him into a position to understand their point of view. Following this up, the first thing a young college graduate should do when he gets his first job is deliberately to cultivate the friendship of the workmen about him. In so doing he will get quite as much, if not more, than he can give. If he does it in a right spirit he will have no trouble over the response and will be doing far more for himself, his employer and his fellow workmen than he realizes.

Last night, coming out on the train, from New York, I read a very significant thing in the "Evening Post," which shows the truth of this in a concrete example, in a far better way than anything which I can say. Here it is, in part:

"A significant incident of the recent strike in Bayonne, hitherto disregarded in the reports of the disturbance, is that, while open industrial warfare was being waged in the streets, and properties in Constable Hook were being patrolled by armed police guards, one plant in the center of the strike district continued to operate with the loss of only a few hours work, due to interference with its men in the early days of the disorder, presenting the spectacle of an oasis of peace in a zone of violence and danger. Although paying a wage scale essentially the same for similar classes of work as that paid in the industries that were paralyzed temporarily by the strike, and although

employing labor of the same grade and nationalities for the same number of hours a day, the General Chemical Company had no trouble with its men. They did not walk out, either in sympathy or under pressure. In fact, they disregarded attempts of strikers to intimidate them, came to the plant, stayed on the grounds, many of them, and kept it running.

"What accounted for the difference?——The company's success in retaining the loyalty of its men can be traced to its friendly attitude toward them, the result of a policy of teaching partnership, developed progressively for several years. ——The unaffected company was obviously distinguished in some fundamental way. In the opinion of its officers, its immunity from disloyalty was due to its policy of democracy in management, of cultivating relations of confidence and frankness with its men, studying their needs and problems, helping toward a solution, and meeting them half way in all differences by a readiness to take any requests under consideration, to learn the reasons for them and, if they could not be granted, to explain why the company was not in a position to make the concessions asked.

"'We are trying to teach our men that they are our partners,' said an officer of the company. 'We had to begin by getting the point of view ourselves, by realizing that the men's interest in the concern could not be disregarded without danger to the concern and that it could be cultivated with advantage. Then we had to educate our managers and superintendents to the same point of view, before we could begin educating our men. Now we are trying to show them something of the problems of business in terms they can understand. .....We publish the cost records in their departments for them to study. When we declare a bonus we explain that it is not a paternalistic gift, but their share of a profit due to the good work they have done. There's no idea of charity; and any man in our office who says 'welfare work' is in danger of losing his job.'

"The company's foremen are instructed to make a point of knowing every man under them personally, of knowing also about his family and habits of life and something of his home problems. It has also been a policy for some years to investigate living conditions among the employees. In these ways the company is constantly informed of the feeling of the employees towards the company, and is conversant with the causes underlying any requests for altered treatment. It is possible to learn of discontent while it is still slight and to meet the desires of the workers on the basis of knowledge of their needs long before matters could come to the point of an open break."

To the inevitable cynical criticism that all this is not meant in good faith the officers reply:

"We couldn't fool our men permanently. We have got to be sincere or they'll find it out. They are keen and would soon know if they were being cheated. As they come to feel that they can count on a square deal from us we find that we can more and more count on a square deal from them. We are learning to work together."

Here is an oasis of successful industrial management in a place which has been a storm center for months. Someone here has learned the art of human engineering. This is not mere altruism or soft sentimentality. It is fairness and right, applied Christianity, good business and good engineering.

Practically all of the courses in our engineering schools deal with science, mathematics and materials, which in no way touch the human problem. Those, however, who have had the opportunity to watch students grow under the influence of Industrial Service Work realize that here is where students will find the spirit which makes such a record as this possible. I can give one instance only.

A talk with one of my own students, a year or so ago, who was in this work, shows how it broadens the viewpoint. "If we fellows here," he said, "were up against what some of these workmen are up against we'd lie right down. There is Tony Gerachi. He is supporting a wife, his mother and four children, beside himself. I have talked with him a lot and know that that fellow is trying to raise a decent American family on $9.85 per week. You talk about his saving? How can he; he hasn't got the margin."

This boy, at least, had found out that a workman was a man, not a brass check. When he realized further that there were ten million Tonys in the United States it "soaked in" to stay. He is the heir apparent of a large business. Some day it may be necessary for him to cut wages, but I promise you that when he does it will be his *last* resource and not his *first*.

These two attitudes, one already experienced and obviously making good, the other young, untrained as yet, but open minded and open hearted, are what we need in the engineer and manager of the next generation. In proportion as this hope is realized, industry will be sounder, management more effective, and every worker from top to bottom, better and happier.

FRIDAY EVENING SESSION

DEAN CODDINGTON, Presiding

We have the great good fortune tonight to listen to a man who, as head of the United States Reclamation Service, has had opportunities to carry out engineering projects on a great scale involving the employment of large numbers of men. In dealing with these men he has been conspicuously successful because he had clearly in mind and heart the great principles of human engineering. I take pleasure in presenting Mr. F. H. Newell, at present Professor of Civil Engineering at the University of Illinois.

THE NEW EMPHASIS ON THE HUMAN FACTOR IN INDUSTRY

THE VISION OF MACHINES

The engineer, if true to his name, is the man of ingenuity. He has had the vision; he has dreamed of improved methods and machines; his dreams have come true. They have taken form and substance in engines of peace, as well as of war. He has made the strength of one man equal to that of a hundred of his forefathers. His machines,—the product of his vision,—perform the intricate tasks which a generation ago required the skill of a score of workers. He has created new necessities before unknown,— in the railroad,— the automobile,— the telephone and in innumerable other devices. He has revised farming methods, one machine or tractor on a farm doing the work of many men and horses— releasing the farm laborer while making a demand for his services in the congested factory districts. He has rendered it possible for millions to live and to find work in the narrow confines of a city, and to bring them food and other necessities of daily life. In short he has raised the machines of wood and of metal to the height almost of human intellect. At the same time he has made conditions such as to permit the mental activity of large numbers of human beings to fall nearly to the level of the machine.

The human units under this development of mechanical efficiency have attained a wonderful efficiency in production of more things at cheaper prices. Success in this direction—on which the eyes of the engineers have been fastened—has been accompanied by serious defects of which he is rapidly becoming aware. The fruit in hand has

crumbled to ashes. What profits it if the world of *things* is gained to the loss by the many of their higher life?

The Widening Vision

The present unrest among the industrial workers is evident. Many fail to recognize, however, that this is the necessary outgrowth of the work of the engineer concentrated on narrow lines. It has not yet been fully understood that he, the man of ingenuity, has by his inventions caused this state of unrest. Shall we punish him? Shall we do away with his kind? Or, rather, shall we say to him—if by the narrow following of your vision we have fallen into this unhappy state it is for you to look about more broadly, to indicate the way and to act as guide in extricating humanity from this slough of discord. It is your duty—above that of all other men—to have a wider vision, to exercise your ingenuity on broader lines and to plan the road around the insurmountable difficulties.

Engineering of Men

In many industries the investment in machinery and equipment represents roughly 50% of the outlay; the amount expended for labor is approximately equal. The engineer has been educated to think almost exclusively in terms of machinery and equipment. He has been regarded as the expert to whom we turn to secure quicker transportation of raw material and of finished products, to speed up the machinery and to increase output per machine. Absorbed in these details he has apparently overlooked the obvious fact that there is a limit to the effective working of this machinery and that limit is set not by the inventor but by the man who must operate it. Almost any one now can go into the market, buy the latest up-to-date machinery, built in accordance with the ripe experience resulting from long years of experimentation. He can equip his factory or construction forces with the finest labor saving devices, but after all this is done he may be unable to hold his own or successfully compete with others. This is not because the machinery is imperfect but from the fact that the foreman and laborers are not utilizing these devices with the efficiency pictured by the engineer or inventor. The condition may be typified by an orchestra provided with the best instruments, each man selected without care, and who united produce discord; they are unable to reach a concert pitch. The relative efficiency on the part of the improved machines may be 80 or 90% of perfection, while that from the human side may be as low as 20%.

Here then is a lack of proper balance. It is of no avail to secure 1% or 2% increase by throwing out the old and procuring better machines if there is a persistent loss ten times as great on the labor side. It is becoming evident that if the engineer is to continue to add to the health, comfort, and prosperity of mankind through inventions, it will be by a larger recognition of the fact that these inventions must aid the men who use them to progress upwards rather than downward to the present unsatisfactory condition where the machine has been exalted above the men.

How can this be done? Is it really the duty of the engineer? Is it not rather that of the statesman or economist? It is easy to shift the responsibility to some other man or profession. Looking the matter squarely in the face, we must admit that of all the types of men and professions the one which purports to lead is that of the men whose business it is to look into the future and to have visions which square in with realities. The lawyer or the statesman is properly concerned with the past, and with the conditions which grow out of it. It is hardly permissible for the man learned in law to consider what the law might or should be; his strength lies rather in ascertaining what the law is. The economist is in much the same position, his concern is with things as they are and while he may discuss what they should be, it has not been a notable part of his training to devise new methods. The engineer, on the other hand, from the very initiation of his technical work is or should be taught not only the fundamental facts but be lead to make application of these in new lines and unexplored fields. The crowning events of an engineer's life are those of research, of trying new things and new methods in ways dictated by a thorough understanding of things as they are.

While it is true that the engineer has confined his thought almost exclusively to the materials and forces of construction, yet his experience is bringing out the fact more and more that human labor is one of the principal forces; that this is governed by laws which he must investigate more thoroughly than he has done in the past and concerning which he must reach a larger understanding. The same training which has made him a success in handling steel and cement must aid him in the far more complicated operations.

How shall this be done? The answer is simple, though the method may be slow and laborious. It is by following the well established principles and practices of careful observation, of correlation of facts and drawing sound deductions from them. There is nothing mysterious about this investigation. While the laws and application

of these laws to human welfare in industry are far more complicated and are subject to more exceptions, yet they are as ascertainable as those which govern the action and reaction of the so-called forces of nature. Such studies may be applied equally well, if not better, in the service of mankind. Our present difficulties are not those growing out of the possibility of knowing and using these laws, but rather of neglect due to concentration of effort on one side only of the problem.

Consider for a moment the time and money now being invested in engineering experiments in some single line as in the perfection of apparatus for electrical lighting, or in the transmission of power, or in the automobile engine. Suppose that an equal or greater amount of money and of scientific skill were concentrated upon one or another of the existing problems of human engineering as contrasted with electrical or chemical. Could we not confidently look forward to a better outcome?

It is not within the bounds of this paper to attempt to lay out the particular lines of research in "human engineering" nor to predict the outcome of these. It is sufficient to note with satisfaction that engineers are awaking to the fact that they have a duty as well as an opportunity and that they are getting down to specific details. This is illustrated in the increasing number of articles which are appearing in engineering periodicals. The progress is shown also in such work as has been done by the U. S. Reclamation Service, which, organized primarily for the reclamation of arid lands, has found it necessary to go beyond the mere preparation of plans and building of great structures. In studying the efficiency and economy of the results, it has steadily been brought into questions of human relation. Beginning with the necessity of providing medical and surgical aid to its laborers in remote camps, it has taken up one after the other questions of keeping liquor out of camp and of providing a counterpoise in the shape of adequate opportunities for enjoyment. It has taken up not merely the proper feeding, but also the housing of its men and their families and in some cases providing school rooms and lending a hand in social activities which tend to keep the men not only on the job but also at their best.

Results Require Welfare

These and other lines of work were not dreamed of at the time the Reclamation Act was passed. They were regarded as wholly outside the domain of engineering. Today the responsible man in immediate

charge of construction regards it as an essential part of his work, as well as a privilege, to take the initiative, being as inconspicuous as possible in all these matters but always looking to the welfare of the men with whom he is in contact. He appreciates that this activity is justified or even required by the consideration of turning to useful ends the forces of mankind as well as of nature. He can show, in his final statement of cost compared to output, the economy of expenditure of time and money in ways which a generation ago would have been regarded as purely altruistic and inconsequential. We are no longer compelled to defend this new emphasis on the human factor, but on the contrary we may properly apologize for doing too little rather than too much. We now know that the efficiency and economy of results are bound up not alone with properly cared for machinery, but more than this with the welfare of the men and women who use these.

Dean Coddington

We have certainly been instructed and helped by Professor Newell's talk and have marvelled at his wonderful photographic slides.

Now we have the further good fortune to be addressed by a man high in the councils of labor and noted for his careful thinking on all subjects connected with the problems of human engineering. I have the honor of introducing Mr. John P. Frey, editor of the International Molder's Journal.

THE HUMAN SIDE OF THE WORKER

A PROBLEM FOR ENGINEERS

By John P. Frey

Before discussing the subject which brings me before you, I desire to express my appreciation of the forward step taken by the Ohio State University in calling this congress.

We are indeed fortunate to have in our State a University which is broadening its influence and which is endeavoring, through such assemblages as the present one, to bring together those who are best informed upon some of our modern problems, for the purpose of securing those necessary exchanges of views which are the first steps to more practical accomplishments.

For the last eight hours we have listened to a series of addresses dealing with the human element which the engineer must understand if he is to be fully successful, and, after such remarkable addresses, it will be a most difficult matter for me, at this time, to add anything which may be of practical value.

From what has already been said at this congress it is apparent that there is no futher need to emphasize the great necessity for an understanding of the human element in engineering. My purpose, therefore, in this closing hour, will be to simply call your attention to some of the problems which the engineer must take up and which he must help to solve with the assistance of such institutions as the Ohio State University.

The addresses and papers already submitted have indicated that at the present time very little of definite character is known concerning many of the problems connected with the human element in engineering. We have only reached the point where we clearly recognize the fact that such a problem exists.

It is self-evident that if we are to have true efficiency in industry there must first be a thorough understanding of the human factor in industry. Those who direct industry must be possessed of broader knowledge than in the past, because the character of our industries has been revolutionized within the last few decades, and in many respects the workman does not occupy the same position in industry which he did a few years ago.

It is frequently the case that in employing labor, the first thought is given to the worker's age and his apparent muscular strength.

I recall an incident which occurred while I was working at my trade and had applied for a position as a molder at a certain foundry. The foreman apparently scrutinized me for the purpose of discovering whether I possessed any exterior evidences of muscular strength and vitality, and seemed to be more concerned with my physical ability to perform the work than with the technical and practical knowledge which I might have of my trade.

Only a short time ago an interesting sight could be witnessed at the employment gate at many of the manufacturing establishments. A large number of men desiring employment would be crowded around the gate or along the enclosure while one or more representatives of the employment department would walk up and down the line, looking over the applicants for employment, with apparently much the same purpose in mind which influences the horse buyer on his visit to the horse market.

We may well ask ourselves whether there is efficiency in such methods.

Perhaps we may secure an important side-light upon the problem we are considering by reversing the situation. Inasmuch as the employer is deeply concerned as to whether the human beings he is to have under his direction are capable of performing efficient labor and must, if he employs them, have their standard of living determined largely by his policies, does there arise a question as to whether the employer is possessed of that understanding of human necessities and that spirit of justice which warrants the community in permitting him to have under his direction, and surrounded by the influences and conditions which he creates in his establishment, a large number of those who constitute the community in the vicinity of his establishment?

Can he be safely trusted with the oversight of the human beings in his employ?

Are the engineers composing his directing staff qualified to be given the right of directing the employes so that their labor will be advantageous to the employer, to the community, and what is equally as important, to the workmen themselves and their families?

We may well ask ourselves this question; "Is the employer's influence on the workman, and that of the engineer, beneficial to the individual, to the industry and to the community, or should the direction of labor be considered wholly from the standpoint of the worker's value as a unit in the production of dividends?

There is one great problem connected with industry of which we know but little and upon which it is most essential that we should have definite information, if the engineer is to have that knowledge without which he is poorly qualified to undertake his responsibilities.

The engineer when dealing with structural steel knows as result of innumerable tests that the breaking strain of the metal is about 65,000 pounds per square inch, but that while this is the breaking strain, the elastic limit is about 35,000 pounds per square inch. When the steel has a strain of 35,000 pounds placed upon it, the elastic limit is passed and the metal receives a permanent change of form; it is no longer able to return to its original form when the strain is removed for a structural change has taken place.

In addition to this, the engineer is aware that if a strain approximately as great as the elastic limit is repeated many times in rapid succession, the steel will finally break even though the breaking strain of a straight pull of 65,000 pounds has never been placed upon it. We are informed that the engineer divides the breaking strain by four in order to determine the factor of safety in the structure which is being erected so that not more than one-half of the load which would be required to reach the elastic limit is allowed to rest upon it.

While we can determine the elastic limit and the breaking strain of steel, we have no knowledge which will enable us to determine either the elastic limit or the breaking strain of labor upon the human being. We have not yet discovered the average workman's normal labor efficiency for productive labor, neither do we know what should be the average number of years during which the normal workman is able to produce efficiently.

One of the speakers this afternoon described the revolution in industry which came with the introduction of machinery. This revolution has been followed in recent years by what many believe to be another revolution, which has been termed scientific management, or "efficiency."

I was talking with a manager of a large industrial plant some time ago who believed in human efficiency, and he was doubtful of the value of this so-called scientific management because it had so far failed to submit any truly scientific data which would show records of long time human efficiency, or the workman's capacity for normal production over long periods of time. He believed that the industrial engineer of today had devoted altogether too much time to the purely mechanical problems of production as compared with the time

given to the study of human beings as producers and as members of the community.

We are justified in looking to the engineer for efficiency. Industrial engineering demands efficiency, but we are of many minds when it comes to determining what efficiency may be. Perhaps efficiency in industry is the ability to do things as well as it is possible to do them by having accurate scientific knowledge of all the problems and the factors involved, and by keeping in mind the fact that the worker is a human being, a member of the community, and a citizen who must take his part and his responsibilities in determining our standards of civilization. Or is efficiency the ability to produce so much physical exertion during a short period of time? Is it the ability to successfully feed material to some semi-automatic machine at a high rate of speed?

Is there a distinction which must be maintained in the efficiency of the workmen of today as compared with the craftsman of the medieval period when self-expression was encouraged and the worker exercised his creative faculties?

Is it without doubt a step in the direction of true efficiency when the engineer experiments with a new type of machine for the purpose of discovering its maximum capacity for production. It may be advisable to speed the machine up to its limit, to operate it at its maximum capacity until it is worn out and then throw it into the scrap heap so that it may be replaced by another. These experiments with machines and with material are essential to efficiency. But how far should the engineer be permitted to experiment with the human being who works with the machine? How far should he go, or should he be allowed to go in his effort to discover the workman's physical and nervous elastic limit or their breaking point.

It is efficiency to endeavor to discover through applied tests, what the normal workers greatest output from the age of twenty-one to forty years may be? Is it efficiency to discover whether the elastic limit, the point where the worker is no longer able to maintain his normal capacity for exertion, is reached at forty, forty-five or fifty years? Is it efficiency to test the worker's capacity for production in the same manner that the machine or material is tested? Is it true efficiency to do these things from the standpoint of mere production and without regard to the welfare of the community, the worker's long time capacity and his individual welfare?

For a number of years it has been a recognized fact that the worker after passing forty years of age finds difficulty in securing a position. It has become a practice in many of our large industrial establishments

to weed out those workers who have passed their physical prime and to continually hire new blood, to throw out into the industrial scrap heap men whose efficiency was destroyed because their physical elastic limit had not been known and the burdens placed upon them had far exceeded that point.

Have these methods, which establish a condition where men are at their prime between twenty-five and thirty-five, given to industry the fullest capacity for production which the workers should be capable of?

Some years ago while studying industrial conditions in Germany, I found that in many of the largest industrial establishments the most valuable workmen were those who had passed the forty-fifth milestone. These men, because of their craft knowledge, their manual skill and their unexhausted vitality, were considered as the most valuable employes in the establishment.

We saw many of these German workmen who had passed the fifty-fifth milestone who were unimpaired physically and capable of fully sustaining the necessary physical exertion required to maintain the full normal production required by the establishment. Something must be wrong in industry when the American worker passes his prime at forty or shortly afterwards. I will not assume to say where all of the responsibility lies, but certainly it is one of the problems which the engineers must study. The engineer will never secure the most successful results from his efforts by endeavoring to use up the worker's vitality in the shortest period of time so that record production can be secured, while the worn-out worker is turned upon the streets to be supplanted by younger men entering into their most virile young manhood.

I would suggest that it is not the duty of the engineer to find out how great an output a man can produce in the shortest period of time, but rather to have in mind the greatest production which the worker can accomplish in a life-time.

Unfortunately we are lacking in scientific data to guide us effectively in approaching this problem. It is recognized that fatigue has a direct bearing upon the worker's physical and mental efficiency, but we have no data relative to fatigue covering long periods of time. The only studies of fatigue in our possession are short time studies which have been made largely in laboratories. No long time studies in either fatigue or efficiency have been made, and there is no scientific knowledge which would enable the engineer to know what the elastic limit of fatigue is.

There are other tremendously important problems which the engineer must work out, if confidence is to be placed in him and safe and satisfactory results follow his directing authority in industry.

What changes must be made so that the young worker will receive an adequate manual and technical training?

What systems and rules must be adopted in industry so that the younger men will be trained to take the place of the skilled mechanic as time passes?

What is to be done so that the monotony connected with much of our production of today will be so understood that the necessary conditions will be established which will prevent the deadening influence of this character of work upon the workmen?

What shall be done in view of the intense specialization of labor in industry which deprives the workers of the opportunity of industrial training?

There is one group in the engineering world who believe that the old time skilled mechanic is no longer essential, that in his place has come the specialized industrial engineer, who, because of the knowledge which he possesses, is competent to direct and instruct less skilled labor to perform all of the work upon which the highly trained mechanic was formerly employed.

It has been recognized for some time that there is a dirth of skilled craftsmen in the United States, and while one group of engineers have claimed that they are no longer essential to industry, as the trained engineer has made it possible to dispense with them, there has been a large group of engineers, who, after having given the problem their attention, have decided that apprenticeship in some form must be re-introduced into industry.

One body in particular, known as the Conference Board on Training Apprentices, has given the subject much study.

This Conference Board was organized on March 6, 1915. It consists of the PRESIDENT and two delegates from each of the following association: The National Metal Trades Association, The National Founders Association, The National Association of Manufacturers, The United Typothetae and Franklin Clubs of America, and the National Machine Tool Builders' Association. The scope of its work is outlined in the following declaration:

"With something like 300,000 manufacturing establishments in the United States, each having its peculiar need of skilled or semi-skilled labor, and with relatively few employers giving serious attention to the proper training of their junior workers, rather depending mainly

for their supply upon the chance of picking them up as needed, the growing scarcity of competent labor has at last forced American employers to realize the urgency of adequate apprenticeship training."

Manufacturers soon found through their studies for increased efficiency, that simultaneously with increased production there occurred a large though preventable waste, which showed itself in three ways —in defective product, in worn machinery, and in increased cost of supervision. And the cause of this waste—a large annual total in most establishments—was easily traced to the lack of fundamental trade knowledge on the part of the workers.

Attempts have been made to compute the large annual economic waste thus occasioned to American employers, but available statistics upon this score are inadequate. In some large establishments, particularly those in metal trades, where the management has been awakened to the necessity of stopping this waste and has undertaken to do so by careful training of apprentices in the practical technique of their trade, it has been found in consequence that the production of defective parts has greatly decreased, the cost of machine repairs has been much diminished, and because of the increased individual intelligence on the part of the workers, the cost of supervision has been materially reduced".

This report is a direct challenge to the claims of those who believe that in the methods of scientific management apprenticeship can be dispensed with.

There are some elements to the general problem which can be readily understood. The employer has invested his capital in business, he has the problem of keeping the Sheriff's flag from the door, as well as that of making progress, building up his business, and meeting the competition of the open market. The question of protecting his investment and making it profitable may become his predominant thought, but the worker's welfare as well as that of the community, make it necessary that the employer's right to operate his business to suit himself and the right of the engineer to direct labor along the channels which seem to be most profitable to the employer cannot be considered as of greater importance than the necessity of protecting the workman's mental and physical standards.

The engineer's problem, if he is to be of true value to the employer, the community, and himself, is to so oversee production that the methods of operation will in no way be injurious to the worker physically or mentally or tend in any manner to lower his standard of living.

Any condition which prematurely exhausts the worker, or which fails to enable him to live as an American, cannot help but lower the standard of efficiency.

It would seem that one of the most important duties of the engineer is to convince the employer, as the result of the scientific knowledge which he has gathered, that true efficiency is the conservation of the worker's physical strength and mental capacity so that the worker can be of greatest benefit to himself, his family, and to industry during a normal life-time.

Briefly then, the problem created by the human side of the worker makes it essential that the engineer should have a scientific knowledge of the physical side of the problem, that he should have a scientific knowledge of fatigue, of the worker's nervous and physical elastic limit, that he should understand that monotony or high speed of production tends to deaden the worker's creative faculties, that to have all of the directing authority and most of the knowledge confined to the hands of a few in authority, means a large army of labor who must depend upon others for all of the necessary information required to perform their labor.

The engineer of the future, if conditions in our industries are to to be properly shaped and developed, must in addition to his engineering knowledge, that is, knowledge of machinery, materials, and mathematics, possess an understanding of psychology and a well-grounded knowledge of economics.

And yet with all of these, there is still one more vital fact which the engineer must understand and that is that in this country the principle of democracy must be recognized and applied in industry.

If it is true, and the statistics supplied by the United States Government abundantly prove that it is, that the conditions under which men labor, and their remuneration for the same, determines their longevity, determines the number of children who shall live, and the vitality with which they enter into this world, then the workman must be given a voice in determining the conditions under which he shall be employed and the compensation which shall be given for such employment. These problems cannot be solved by any one group with justice and with satisfaction to the other.

In addition to all of the scientific knowledge which the engineer must acquire before he is capable of undertaking the direction of labor he must learn to meet with the workers and discuss the problems which affect them as workers. He must freely recognize their most

necessary right to have a voice in the determination of the conditions which affect them in industry.

All of the knowledge which the engineer may acquire, will fail to secure successful results if he feels that his position is to be that of the arbitrary director and overseer of those who toil in our industries.

The right of the workers to express themselves, the principle of democracy in the relationship of employer and employee are fundamentals for a permanent and prosperous industrial country.

SATURDAY MORNING SESSION, OCTOBER 28

PRESIDENT THOMPSON, Presiding

The gentleman who will address us first this morning has been for a long time interested in the maintenance and direction of men from the point of view of a railroad man. He has been interested in a good many affairs outside of railroading in which the life and health of men have been involved. With his wide experience I am sure he is full of suggestions to students. He is a graduate of Cornell and knows students. I have great pleasure in introducing Mr. Beahan, Engineer for the New York Central Railroad who will address us on "The Engineering of Men".

"THE ENGINEERING OF MEN."

WILLARD BEAHAN

Some three years ago I was asked to address a meeting of the Cleveland Engineering Society, and they gave the rather ambitious title of "The Engineering of Men" to my address and as I had thus far had no strikes I was to try to tell them how I did it.

Now you must bear in mind the genesis of this talk. I must use the first person singular pronoun even if I put in a good deal of ego. I believe we can speak from our own experience with greater interest and greater propriety. I have heard it said it is always better to have a few ideas raised on your own premises than to have an orphan asylum full of ideas raised on somebody's else premises.

I served early under General Dodge, a man of splendid type, who knew how to handle men. So, many ideas I have, I had gotten from General Dodge when I was a young man.

"The most difficult branch of engineering and at the same time the most important is the engineering of men." Those are the words of Robert Stephenson, spoken about 1830. Robert Stephenson was the son of George Stephenson, and George Stephenson built the first locomotive. The Stephensons have been called the fathers of railroad engineering. Robert Stephenson outlived his father, and during the last years of his life he laid down this great human law. George Stephenson, the father, laid down another law,—"Competition is impossible wherever combination is possible." So you have those two laws

of son and father. They are the horizon laws in the engineering of men. We have beeen trying to compel our railroads to cease combining and have found it impossible, and engineers in the last ten years have been going back to the teachings of Robert Stephenson.

It would never have been possible to have had the vision in human engineering we have, had it not been for Robert Stephenson. When a man has a broad, comprehensive view, he can lay down horizon laws. Services are like everything else, they are great and wonderful because civilization needs them. The growth in railroads has been rapid, but I maintain the engineer can explain his own plans better than any man can for him. I don't propose to take a back seat with any lawyer talking engineering. The first law in handling men that I would lay down is an old one. The first needs are always old, You will find it in the book of Luke, chapter six and about the thirty first verse, "Do unto others as you would have them do unto you." It takes a brave man to carry it out. If you do not include this rule in your practice you will be a failure as an engineer of men. Whatever else you do, if you can't put yourself in the place of the other fellow, you will fail. General Dodge used to tell us it was a great deal harder to find a man to take *care* of a brigade during the great Civil War, than it was to find a man who could "fight" that brigade, more difficult to find how to take care of three thousand men than to lead them in battle. I do not want you young men to think this question is not worth learning or that it will not be beneficial to you.

Let me cite one fact of history. Our national climax, historically, certainly the greatest in my life time, was the battle of Gettysburg on July third, 1863. It was Pickett's charge that would turn the tide, that ought to settle the war. The brigades were lined up by transits so they wouldn't bunch. The Union forces could see them coming. It happened to be the second corps of the Union army under Hancock who had to withstand that great charge. There was open ground to cross for nearly a mile. That charge came nearly succeeding. I will not go into detail,—Hancock was shot while sitting on his horse as the charge started and a piece of his saddle was carried into the groin, making a bad wound. In his hand was found, as he lay wounded, the usual tablet officers used for writing orders. On it he had nearly finished what order? Why, to his Commissary officer directing that a ration of fresh beef be ready for the soldiers of the second corps that night. At what he knew must be the summit of his career, General Hancock put first the care of the men in his charge. I think

you fellows in going out can well think of taking care of your men. If you don't you won't have any command to lead.

The third law is this: Carry on your heart the men you carry on your pay roll. I was division engineer on the Lehigh Valley Railroad when Amos Turner was master mechanic of that division. When going through his shops he would speak to every one. Upon being questioned about it, he said, "I started in when I was a boy, I know them all, it is a little thing to speak to a man and ask about his wife and the home." There were strikes in other shops, but in this one they had no strike. Simply because Amos Turner carried his men on his heart, and they will never have a strike as long as he is there.

When I became connected with the New York Central Railroad the steam shovels were put in my charge. There were two labor unions in that craft, bitterly opposed to each other. When the men asked me how I stood in the matter I said, every man may join one union or the other union or no union or both unions and must allow every other man that same priviledge. I carefully made a seniority list and promoted men according to that list. I let them work as near home as I could. I told them if they heard anyone of their family was sick to turn their machines over to the next oldest man in their crew, wire me of it and take the first train home—that they must take care of their families and I would take care of the Company's interest. Remember that men are human. If you don't you will have strikes. If you do not feel an interest in the men under you and in their families let some other man handle that force for you *never can*.

The engineer must have personality. I mean that kind of person ality that Edwin V. Sumner had who died in the second year of the war This is the compliment paid to him by General Francis A. Walker:

"Jupiter shining full clear and strong in the midnight heavens might be the disembodied spirit of Edwin V. Sumner. If the second army corps had a touch above the common, it was derived from the gallant old chieftain who first organized them and lead them into battle."

I follow in history this personality and this is the spirit you must have in your school life. Be such that the other boys can pick you out for it. The young man who has this spirit is a leader in any way. The engineer that gets along well with his men is the engineer whom the "other fellows" take a fancy to.

The next quality is discipline. Some man has well said, that while battles have been won by poor generals no battle was ever won by a debating society. I don't mean for you to use army discipline

but all of it save the shoulder straps. I mean the man in charge must have undisputed charge. He must have the authority. Then he must be right, legallay and morally. He must be just. He must have sympathy. He must know human nature. A thing is not right because he says so, but he must say so because it is right. He may be a despot but he must be right. The engineer will be held responsible for these men and all other men under him, when he stands the last day before the great bar of justice. He must administer discipline. He must create about him a despotism as it were, controlled by humane principles.

The last quality needed is fair treatment. It may be the master and servant idea. We can never get back to it-those days when the boy was taken into the master's family to raise. The men with the brass collars in railroad service are the men who take the place of the master. Pay up, agree to pay to the last cent and pay promptly. Pay enough but be reasonable. You can never buy loyalty. Pay promptly, and pay in full. Occasionally you will have trouble. The human machine is a great machine, and it requires a great deal of knowledge of psychology in dealing with men. Though I haven't had a strike, I have seen a little trouble. The engineer must let the human element enter in in dealing with his men and must listen to their troubles and be one with them in solving them. He must forget self, although, as Kipling has the old cavalry sergeant say while waiting for the order to charge :—

"He's just as sick as they are,
  His heart is like to split,
But he works 'em, works 'em, works 'em
  Till he feels 'em take the bit;
The rest is holding steady
  Till the watchful bugles play,
And he lifts 'em, lifts 'em, lifts 'em,
  Through the charge that wins the day."

At one time in my experience I remember of having a little trouble when I was doing some work in which Mr. Gould was interested. I could not locate the trouble; I remember I had to call in three men who had been with me for nine or ten years. I had found out they had not treated some of the other men quite right. I said, "This must be stopped; I am surprised after all these years I have to speak to you." The men looked ashamed, and one old fellow with tears in his eyes said, "I am ashamed". Oftimes some little thing will come up and will be carried too far.

You, as engineers of men, are bound to have some trouble, when handling the laboring men more than others. In handling common labor there should be no question about authority—I have already touched upon that enough. If you are put in charge don't be foolish enough to allow other men to come around and mix in. Men must get instructions from one man. You must not be fussy and nervous; see everything, but don't notice everything. You may see things which are not going just right, for instance around the cook house. But you must not notice everything. The cook's temper is often sorely tried. It is the same way with the foreman of the gang; don't notice everything; don't notice more than is necessary. In handling labor you must be right. You can't fool a hundred men, you might fool one, or you might fool them one day in a month. But you must have the right on your side, not only legally but morally and mentally as well.

Let me illustrate—We were building the Cascade tunnel. I was superintendent and had four hundred men working in shifts of fifty for eight hours. I had my headquarters at the east portal. One morning when the snow was coming down in "sheep pelts", for I have actually seen it fall that way, as I passed the cook's and commissary's house before I got to the portal, I saw men coming out of the quarter houses; I knew at once men would not be coming out in such a storm, as the snow was twenty to thirty feet deep, unless they meant trouble. I waited. I said, "Good morning, boys, What's up?" The answer came back that they were going up to the cook house to hang the commissary clerk. I told them this was foolish, I was not going to let them do a thing of this kind. "You would be committing murder, and besides I am not going to let you carry on a little festivity of this kind when I am not invited." After some parleying I told them this was all wrong and they must not do it. Most of the men dropped back; about twenty stood their ground. Some had been drinking. I realized that I must act. I drew a mark with my toe across the snow. I said, "You say you are going down there to hang the commissary clerk. The first five men who cross that mark, I will kill. In that way I will expect to get the man who started this muss." We had been together some months and I had always kept my word with them. The leader of the gang, an Irishman with his shirt sleeves rolled up so as to show the red sleeve beneath, seemed to sober up. Whenever an Irishman thinks he is going to die, he gets sober. (Laughter). Mike said, "Well, Super. what is your proposition"? "You go back to your quarters." I told them I would see the cook and commissary clerk and that the men should send a delegation to me. It was satis-

factory and in twenty minutes they went back. Why did they go back? They went back primarily because they knew that I was right. Eighty percent of them saw that I was in the right. The rest went back when they saw they *had* to go back.

You are in no danger even with a hundred men if you are in the right. You can never control a hundred men if you have an idea your life is too precious to take a chance. You must be right and then be not afraid to be killed when you use your authority.

I never make or have trouble with the labor unions. I let Unions come in and organize, but it is my job to stand nearer those men than any organizer. I can do more for those men than Unions. My God has held me responsible for those fellows. The labor union is not a law of the land, in no way are syndicates or capital organization laws of the land, politics is not a law of the land. These are secondary. Take the words of Daniel Webster:

"Aloft on the throne of God, and not in the footprints of a trampling multitude are the eternal principles of right and justice which no majority can displace or overturn."

Don't have majority rules; sometimes majority is overthrown. I am inclined to think the majority is not infrequently entirely wrong.

I have here a copy of the Engineering News, I am not an agent for it, but here is an editorial on " An Engineer's Plan to Prevent Strikes on Public Utilities." by Mr. Towne of the Yale and Towne Company. "The most important element in Mr. Towne's plan is the provision that every employee of a public utility corporation should have a definite written contract for a stated term of service. During that term of service he should be neither at liberty to quit his service with the company, nor should the company be free to discharge him. If either party to this contract breaks it, a stated money penalty should be forfeited to the other party.

The underlying basic idea on which this proposition rests is that in the operation of public utilities,where the public has a right to continous service, the old idea that the employer has a right to discharge a man without notice, for any reason or for no reason, should be done away with, and also the idea that the employees either singly or in combination, are free to quite without notice.

The recent threat of a nation wide railroad strike, with the surrender of the Government to the railway brotherhood demands, has had one valuable result. It has brought home clearly to the mind of every thinking man the conviction that in some way or other the right of

the public to uninterrupted service on public utilities must be established.

There is no doubt whatever that this is the logical way to prevent strikes on public utilities, but the question is; How can this plan be put in operation? Labor organazations will exert their united influence against such a proposition. The capital invested in public utilities has to yield certain of the rights and priviledges which it enjoys when engaged in private industry and submit to public control. It does this willingly because of the other priviledges which it receives. What priviledge can be given the employee of a public utility company that will compensate him so as to make him also willing to submit to public control and to relinquish his right?

It is a real and important advantage to the workman to have a definite written contract of employment for a definite time. He is given something that he has never before possessed—a legal right to his job. This in itself is a very great gain.

I have taken a long time. I hope you young men have gotten some little good from what I have said. I love my work: I honestly believe I can do more good there than anywhere else. The engineer's fault primarily has been that he has kept too much to himself and is not interested enough in public affairs. He must feel the need of doing something for humanity in all directions, and it is up to you and up to me. This handling of men is the engineer's job, and he must go to it with enthusiasm and with humanity in his soul. I repeat in closing the words of Foss:

"There are hermit souls that live withdrawn,
  In the place of their self content;
There are souls, like stars, that live apart,
  In a fellowless firmament.
There are pioneer souls, that blaze their path
  Where the highway never ran;
But let me live by the side of the road
  And be a friend to man."

Dr. Thompson

It is very fitting that we should be addressed at this time by the man who first proposed this meeting. I take pleasure in introducing Mr. Fred Rindge, Jr., of the Industrial Department of the International Committee of the Y.M.C.A.

NEW IDEALS IN HUMAN ENGINEERING

FRED H. RINDGE, Jr., Industrial Department
International Committee of Young Men's Christian Association.

As we near the close of this remarkable congress I have been asked to bring to you a brief summary. There has never before been held in the United States a Congress of this kind, and Ohio State University deserves very great credit in pioneering it. I earnestly hope that many colleges will catch the vision you have caught and promote similar programs.

How can we summarize the Congress of Engineering? Though entirely inadequate, these four sentences occur to me:

First. As far as the students are concerned, college "bred" does not mean a four years' "loaf."

Second. The college graduate looking for a soft place will usually find it under his hat.

Third. The great task of today is to get the working man educated and the educated man to work.

Fourth. Although it is a great thing to be an electrical engineer, a civil engineer, a mechanical engineer, a mining engineer, etc., it is necessary that all of us shall be primarily *human engineers.* And this implies vast opportunities and responsibilities.

I trust that a printed report of this Congress will be published and sent all over the country. I have never heard a more admirable series of addresses, a more fair-minded presentation of different points of view, in regard to the great industrial and social problems of the day. How significant it is that all these speakers from various parts of the country and with different view points hit on the same central idea, that after all, the big thing today is the human side of the job!

Perhaps some of us have been a bit confused amid the number of good things, but I am sure we can never forget the same, clear emphasis on the increasing importance of the human factor in industry. I overheard one engineering student say, "Gee, I hadn't any idea all this stuff had anything to do with engineering." I fear many other such students, all over the country have failed to realize that the *humanics* of industry are of more importance than the *mechanics.*

Let me summarize briefly some of the significant things that have been said at this Congress:—

C. R. Dooley emphasized the need for character, initiative, originality, and other sterling qualities in the engineer of the future. He said "We believe that every man in our employ has only one life to live, and is entitled to the best life of which he is capable." Those are significant words.

President Mitchell, an expert in American history, spoke from the wealth of his experience on the timeliness of this Congress. "The type man of America" he said, "is the engineer." His emphasis on the human touch, was splendid. He showed that the ideal man must be one who has "an international mind."

C. R. Hook put his fist in our face, and we were delighted to have him. Most of us will never forget the emphasis he put on the fair treatment of man. As one of the speakers said, "no man could say the things he said, if he were not living the life himself." Do you recall his statement: "You can have all kinds of welfare work, but if you haven't got the man you haven't got much." He told a splendid story about the man in the shop who made so many fool suggestions, to which he had to litsen patiently, but the day came when that man made a suggestion that was worth all the time he had taken. The suggestion was worth its weight in gold to the company.

Captain W. P. White, gave us a splendid, courteous emphasis on the National Association of Manufacturer's point of view. Perhaps we did not agree with all that he said, nor did we agree with *everything* that the labor leaders said later, but we surely got a big conception of the real problems that we, as college men, have got to face. We got the impression that many manufacturers are absolutely sincere and are anxious to do the right thing. But it is often exceedingly difficult to discover what the right thing is.

The second day gave us a portrayal, seething with the human touch. There is no man in the United States who understands the foreigner and how to teach him any better than Dr. Peter Roberts. By way of illustration, he brought us the challenge of the European war. "What are *you* doing for *your* country?" I am sure we felt the great call to larger service among our foreign born brothers. Splendid emphasis was laid on the fact that some of us will never feel at home with the different nationalities in heaven until we learn to feel at home here on earth with these nationalities.

Mr. Bush, the presiding officer at this session remarked at the close of Dr. Roberts' address: "We need a million engineers like Dr. Roberts. It is up to you!"

Mr. C. J. Hicks, a man who has had years of experience in these things, clearly emphasized the real desire of an increasing number of business men today to solve the labor problem, not from the top down, but from the bottom up. He emphasized the thought of letting the men themselves determine their own rules. The new industrial representation plan of the Colorado Fuel and Iron Company was a splendid illustration of this wise tendency.

I am sure President Thompson's remarks, to the effect that "what is right in the final analysis pays, not only from the human standpoint but from the standpoint of dollars and cents," came home with a new meaning to the 1200 people in the audience.

Mr. W. A. Grieves in his paper on the "Handling of men," emphasized the fact that what we need most in our engineering schools is more education in understanding the human factor. Where welfare work has failed there is always a real cause. I heard one man say, "Most American workers would rather have self respect and some dirt, than be advertised under other conditions." As a leader, so will be his men. If a department head is mean he will have a lot of mean men under him. He told us there was too much money spent in the employer and the employee fighting each other, and *not enough in getting together*. "Co-operation and not disintegration is the real need."

Mr. C. R. Towson gave us a much-needed conception of the place of Christian and social agencies in the welfare program. No man in the country is closer to the heart throb of industry in its human relations. I hope we will never forget the wonderful portrayal he gave us of how industry needs, above all else, *character*, and that agencies like the Young Men's Christian Association produce character. He touched on the spirit of the workers. "The policy of the company can be no bigger than the interpretation put upon that policy." The Y. M. C. A. is used for the benefit of both employer and employee. He might have told you that this organization has 100,000 industrial members, and reaches 400,000 more in various lines of extension work. This is in addition to as many more workingmen reached by the railroad Associations. Some of you coming engineers and business men will naturally look to this organization as an ally in your welfare work.

Mr. E. L. Shuey who wrote one of the first books in this country on welfare work, has been for twenty years vitally interested in working out these human problems. "The challenge today is a challenge for service. To be effective it must be conducted from the bottom up

not from the top down." His splended personal illustrations and how this principle really works out in practice were illuminating

Then we had the labor point of view given by Mr. J. A. Voll. It was a clear presentation of what the engineer must understand—the labor union's attitude toward the great industrial problems of the day. It was encouraging to have his opening statement. "Labor and Capital and the Public, ought to be thankful to those who made this Congress possible." He told us that *ignorance was the real curse of industry.* In spite of all the helpful things the millenium is a long way off, and there is a big job ahead of us! He felt that the employer and employee are getting closer together, in spite of seemingly glaring exceptions.

You will never forget the splendid presentation which Professor J.W.Roe of Yale gave us of the Industrial Service Movement idea. He showed us scientifically that the way to get the point of view of the workingman, to learn how to handle men is to engage in practical service with these men. As he spoke, I know a good many of us felt like going out immediately and organizing a class in teaching English to the Foreigner. If you desire to get more of Professor Roe's ideas on this subject I would suggest your reading his paper presented before the American Society of Mechanical Engineers on "Industrial Service Work in Engineering Schools."

I wish every one could have been here for the inspiration given us by Professor F.H. Newell, who has for twelve years been active in the U.S. Reclamation Service. He showed us some wonderful stereopticon slides, illustrating superhuman tasks conquered by human activities. After all, those 3,000,000 acres of land were reclaimed "for the benefit of humanity." The thing could never have been done had it not been for the true regard for the human factor.

Mr. John P. Frey gave us a different point of view on scientific management and labor problems. "The question is, not only is the working man fit to work, but is the employer fit to employ." Hours and wages are the worker's life. How vital therefore it is, that we should determine these things fairly. As we have heard representatives of capital and labor at this congress present their divergent views on certain big problems we have realized how much there is to be said on both sides and *how essential it is that we understand both sides.*

Mr. Willard Beahan's great address might perhaps be summed up in his statement "The man you have on the pay roll, you must carry on your heart also." Mr. Beahan comes to this conclusion not from any sentimental reasons but as a result of many years of wide practical experience.

It is a difficult task to summarize a conference of this kind. All this has gotten on our sensory nerves. Has it gotten on our motor nerves? We have heard some one remark, "I have tried brotherhood once and it failed." This reminds me of the story about a man in an Insane Asylum, trundling a wheelbarrow upside down. When asked why he didn't turn it over right, he replied, "Not on your life. I tried that once, and some one put bricks in it!" No matter how many rebuffs or difficulties we may meet let us realize that it pays to recognize justice and humanity as cardinal principles in our work and life.

As we sit here in comfort this morning my thoughts turn back to the European war. 43,000,000 men and boys have been called to the colors of their respective nations. The war is costing about $100,000,000 a day.

Directly and indirectly the great industrial and social problems of the world are costing more than that! The call in Europe is for volunteers, and I say to you that the call for volunteers for service in the industrial world is just as great! Our President has wisely asked us to observe toward the war an attitude of neutrality. But we have not been asked to have such an attitude toward these great industrial questions. About 4,000,000 men have been killed in this fearful war. Considerably over 5,500,000 have been seriously wounded. About 6,000,000 have been taken prisoners. A great leader in Europe has said, "Why doesn't your country demonstrate a moral equivalent for war?" True preparedness does not lie in battleships and armies, but in the realm of the social and economic. Why may we not fight for peace, and for human brotherhood instead of for human hatred? One of our secretaries, recently returned from the war zone, tells of one man just recovering from severe wounds who was told that he could not return to the trenches because his arm had been shortened in healing. Without hesitation he had his arm rebroken and stretched in order that he might go back and fight for his country. This is human heroism we admire.

And this is the sort of heroism and spirit which as college men we must show as we face the trenches of industrial handicap, accident, poverty, vice and misunderstanding. Must we have war in America before we are really awake to our responsibilities; before capital and labor can get together on a platform of understanding and mutuality?

Now let me come to a very practical suggestion. We have become convinced that we must acquire a larger knowledge of these problems from first hand experience, and that we must learn how to handle men. You can do this by taking time now, once or twice a week to

teach a class of foreigners English, help a group of American working men in mathematics, mechanics, etc., lead a club of working boys, etc., etc. You will get out of such an experience far more than you will put into it. This is the philosophy of our whole Industrial Service Movement, which has been growing so rapidly throughout the country in the past seven years. The Movement has now spread under the auspices of the Young Men's Christian Association, on the broadest possible basis, to over 200 different colleges. At the present time over 4,000 engineering students are actually reaching 100,000 working men and boys regularly each week in worth while service. They are undertaking this work in the finest kind of a spirit, not going down to help others or asking others to come up and be helped, but rather going with them in a spirit of brotherhood and service. (Mr. Rindge then gave a number of interesting incidents of definite work being undertaken by college students, mostly engineers, throughout the United States. Out of the wealth of his experience in this work he made perfectly clear that this is a work which "blesseth him that gives and him that takes." For further details readers of this report are respectfully referred to the pamphlets and other material published by the Industrial Service Movement, International Committee, Y.M.C.A., 124 East 28th St., New York. This material will be sent on request.

I am glad to say that about 100 students from this University have engaged in work of this kind with remarkable success during the past year and the number of those interested is rapidly increasing. Call this social service if you will but it is far more than that. It is human brotherhood worked out on a practical basis and with the result that men are gaining experience which will be invaluable to them in these coming years. As I meet college graduates all over the country I feel increasingly that those who have taken time in undergraduate days to do something worth while for somebody else are very largely the men who are making good in a large way whatever their profession today.

We figure on a thousand engineers graduating each year from American colleges after having had a close touch with this Movement. Just the other day I heard one such man say: "I just turned down a position which would have paid me $5,000 more a year than I am now receiving, because in the new position I wouldn't be free to deal with men on a fair and Christian basis. I would rather stay where I am and see that my men get a square deal than take any position, at whatever salary, where I couldn't work out the humanitarian ideas

that I so firmly believe in." These are the kind of engineering and business men we need in America. There are over 200,000 college graduates in the United States today. Suppose every one of these had gotten this kind of a vision back in his college days. If such had been the case this old world of ours would be a different place to live in.

For a more complete treatment of the Industrial Service Movement and its activities may I respectfully refer you to my article in "Industrial Management, the Engineering Magazine," for November 1916. I can take time for but a brief mention of the following activities which I firmly believe should be carried on in every engineering school in the United States:

First. A supplementing of theoretical training by practical service among working men and boys, such as has already been indicated.

Second. A definite course required for seniors on "The Human Side of Engineering". (Complete outline of such a proposed course will be sent on request.)

Third. A series of lectures by employers, labor leaders, social workers and others. Just such a series of addresses as we had here at this Congress.

Fourth. If possible, a Congress, similar to this one which we have just held.

Fifth. A weekly voluntary discussion group of interested students to consider industrial and social problems and their *personal responsibility* in this matter. In a sense this might become a normal training group for those students who are actually engaged in service.

Sixth. A bulletin board, or several of them in the engineering building containing the latest material on industrial betterment and the human side of engineering. This to include welfare publications of leading companies and business concerns throughout the United States, photographs, the best publications of various organizations, national and otherwise, dealing with these questions. (A list of such agencies will be found in a book entitled "Among Industrial Workers" published by Association Press, New York City.)

Seventh. Engineering inspection trips to include as much attention as possible to the human side. The need of this is perfectly apparent. Just the other day I asked a group of students who had been

out on a three weeks' inspection trip, what they thought of the welfare work of a certain company. They had spent a good many hours in this Company but had seen practically nothing of the welfare work. I asked them what they thought of the Safety Department and they knew nothing about this. They had been studying simply the technical aspects of their work and the professors in charge had failed to show them the human side.

These ideas have been worked out with great success in a number of colleges and I see no reason why they cannot become a part of the program of every engineering college.

Eighth. A meeting of seniors as they are about to graduate from college, putting up clearly to them their responsibility for service in the industrial world after graduation. As far as possible Professors, secretaries of the Industrial Service Movement and others should try to keep in touch with these young men after graduation and try to help them in their larger efforts for industrial and social betterment.

As I travel around the country I seldom visit a city or an industrial operation without meeting or hearing about some man who "got the idea" back at college. Three thousand such engineering graduates are now on our lists, and the number is increasing at the rate of about 1000 a year. To quote from an article in the May issue of The Iron Age: "Recently in a western city an industrial welfare committee was organized but no one seemed to know just what to do next. Two men were then discovered who had been in charge of the industrial service work while at college. These men knew exactly what to do and how to do it and the problem was solved. One graduate has charge of all the accident prevention in a great company; another has built a $40,000 "Service Club" for his employees. Several have become welfare secretaries of large business concerns and others have associated themselves with various welfare agencies determined to give their lives to the cause. One of these is leading the Industrial Service Movement in New York City and has 200 college men working as volunteers under his direction; and so it spreads."

Finally, let me say, all of us may as well make up our minds that there will be obstacles and all sorts of difficulties to face in reaching our ideal. I am reminded of a story of an eagle making its flight across the sky and suddenly struck by a terrific storm. For a long time the eagle was beaten and battered by the wind, was struck down

in its flight and seemed about to be dashed to pieces over a great cliff. Apparently the eagle was thoroughly discouraged and about to give up hope. Suddenly, it turned around and *faced the wind*. Slowly but surely strength was given, and it mounted up and up into the sky triumphant. We cannot all be eagles but, in the highest sense, we can all be men!

Dean Coddington

Mr. Rindge has brought to focus the teachings of the previous speakers in a most excellent way and we all have a clearer view of the meaning of "Human Engineering".

Now we have with us a college man who is actively engaged in manufacturing who will express to us some of his convictions on our subject. I am pleased to introduce Mr. L. T. Warner, of Warner Brothers Company.

NEW IDEALS IN HUMAN ENGINEERING

MR. L. T. WARNER,—Warner Brothers Company, Bridgeport, Connecticut

When I went to Oberlin College twenty years ago, I remember our professor in Psychology impressed upon us this thought, "That which is unexpressed dies."

If you men and women who have attended this Congress have caught the vision of what constitutes the all around job of the man or women who leaves college and enters the realm of industry, you have felt something stirring in your hearts and minds. You have perhaps determined to do your part.

But all the resolutions you have made will disappear, if they do not receive some expression in your life. You must do something now, or when you go from college out into industry, you will be just as unprepared to meet the needs of men as you were before this Congress convened.

What are you doing to prepare? Probably the greater part of you engineering students, when you go out from college, are going to be in industry. You are going to be in direct contact with the laboring man then. Why not now? There are ways to do so here in College. You can serve laboring men. You can study laboring conditions.

Perhaps we have been too much decrying book leaning in this Congress. So much emphasis has been put on the human side that we have not said how much could be learned from books or the ordinary methods of college instruction. But the instruction and inspiration we have received here in this Congress have been by college instruction methods.

I believe there should be a course in "The Human Side of Engineering" in every engineering school. I believe that college men can and ought to learn something of the human problem, from a study in books and from the lecture platform; not just coming together for a day or two and then going away. There should be a regular course. There could be in every University a course wherein such topics as have been discussed here will be put before the students in a logical manner, preferably taught by the professor with help of outside men from the world of industry, who will be glad to give their points of view. Without this training your education is incomplete.

You may have this course in the Ohio State University. If you have not, there is not a professor in this room but will bear me out that it is the function of the University to give information about the human side of the engineer's job, as well as the technical training in the science and mathematics of his profession.

You have laboratory work in your technical training. You must do laboratory work in your training in human engineering. In Columbus there are numerous factories with all kinds of men, and all kinds of work to be done for them. Some want shop mathematics, some a friendly interest. Some need the English language, and if they do not get it before very long, they are going to have their hands cut off in the machines.

There are men in your own University who can show you how to teach foreign born working men the English language, how to conduct classes of all kinds among industrial men. This is laboratory work. But it cannot be required. It must be done in a spirit of sacrifice and service, not directly for your own benefit but because you are interested in men.

You are alive to the importance of knowing the workingman, if you are to be successful engineers. You know how to put your new enthusiasm into practice. Study the men. Work with, and for the men. So will your present determination not die, and so will this Congress live in your lives and in the lives of working men.

DEAN CODDINGTON

Now we are to be addressed by a man who represents an entirely different point of view, that of the economist, and who is also the only representative of this university on the program, Professor Horace Drury of the Department of Economics and Sociology.

SCIENTIFIC MANAGEMENT AND PROGRESS

HORACE B. DRURY

The subject of this address has been announced as Scientific Management and Progress. It might have been put, just as appropriately and perhaps more clearly: Scientific Management: Yesterday and To-morrow. There have been times when buildings still new and at their best have been torn down to make room for larger and more modern structures. Just so, the systems that men built yesterday are to-day subjected to an acid test of criticism; and, even in their first flush of victory, their principles are modified or enlarged to meet the new demands of a new day.

Such a novelty of yesterday was the practice and outlook known as scientific management. To-day, it can no longer be called new; but it has become a well-charted highway through which men must press on if they are to grasp the riper principles of the on-coming era. The purpose of this paper is to explain what scientific management is; to note in what respects and how admirably it has fitted in with the industrial movements of the past thirty-five years; and then to search for any fresh adjustments, which, perchance, the system may be asked to make if it is to be in full accord with the world of to-morrow.

The scientific management which we are to consider this morning originated in the eighties. It was the answer, however, to industrial conditions which began to take definite shape soon after the close of our Civil War. The million soldiers who had been engaged on the northern side in that great struggle were, after their release, a great factor in peopling the agricultural west, and swelling the labo force of a new manufacturing east. More important, five millions of immigrants flocked to the United States during the two decades 1860 to 1880, and another five million during the single decade 1880-1890 This occupation of our public domain closed the frontier safety valve for turbulent or ambitious spirits, and brought the east, for the first time in its history, face to face with a serious labor problem.

The manufacturing industries into which the nations's surplus energy then turned had, the middle of the century, been scarcely a promise. But by 1870, the number of wage earners had already increased from less than one million to more than two millions. By 1890, the new army had reached a total of four and a quarter millions; while

the capital invested had grown from scarcely more than a half billion in 1850 to six and one half billions in 1890. That is, less than one-twelfth of the capital invested in manufactures in 1890 had originated earlier than 1850. The two periods of great gain were the Civil War decade, and, more especially the eighties. From 1880 to 1890, the number of wage earners in this country increased by one and a half millions, a growth twice as great as in any preceding decade, and fifty per cent greater than that which was to mark the nineties. The gain in capital during the eighties was three and three quarters billion dollars, or more than three times as great as in any preceding decade, and greater by about half a billion than the advance that was to be made between 1890 and 1900.

Even more phenomenal and significant than the expansion of manufacturing was that revolution in method known as the introduction of large scale production. Government reports and general opinion unite in placing the date for this transformation at about 1880. In the iron and steel industry the movement was well under way in the seventies, but in a greater number of industries the apex was reached in the eighties. Neither before nor after this period was there anything like as rapid a swing towards concentration, perhaps not even after 1900. It is remembered that the first trusts were also formed at this time, the Standard Oil trust in 1879, and the first sugar and whisky trusts in 1887. In short, for the first time in American history it had now become common for large numbers of workmen to be employed under one management.

Another aspect of industry, significant in its bearings upon the origin of scientific management, was the new foreign element employed in the shops. The year 1882 was to mark the flood tide of a great wave of immigration, the 789,000 who came in that year setting a record which had never before been rivaled, and which was not again to be equaled for twenty years. Very nearly one-third of all the persons engaged in manufacturing, mechanical, and mining pursuits were already in 1880 natives of foreign countries, with the greatest immigration yet to come. The foreigners were mostly unskilled laborers, occupying the lower places in the industrial scheme, and that rapid shift in the source of immigration from northwestern to southeastern Europe, later to be so noticeable, had already begun.

It is seen, in short, that by 1880 or shortly after, most of the industrial problems of our time were on hand, and in that initial period when they were the most likely to do mischief, and to excite alarm. The rapid elimination of the frontier, which was to be practically com-

plete before the end of the decade, was already beginning to confine ambitious workmen to subordinate positions in the east. The rapid increase in the size of many industrial plants was separating the employer from his employees. The foreign third of the workmen, many of them newly arrived immigrants, were not capable of ready co-operation with their employers, even had other conditions been favorable.

The resultant of these new forces was, on the one hand, the beginning of the modern labor movement. Prior to the Civil War, there had been in this country no union movement of other than of transitory importance. Unions began to become influential in the latter part of the Civil War period, and, barring a few years of depression following the crisis of 1873, their membership steadily increased in numbers and influence. Especially after 1878 a period of growth set in, many of the unions finally merging themselves in the Knights of Labor, which by 1886 claimed 600,000 members. The first strikes of national importance which the country had ever had were the violent and widespread railroad strikes of 1877. During the eighties the losses arising from strikes increased rapidly, reaching a climax in 1886. The few years prior to 1886 constituted, indeed, the greatest strike period in our history, Since 1886, the number of strikes has not kept pace with the growth of population, much less with the growth of industry. But more important than the strikes of this period was the chronic disloyalty and inefficiency which marked the daily activity of thousands of workmen. The lack of contact and sympathy between employer and employee had weakened and perverted the entire industrial system. Limitation of output, soldiering, carelessness, these were the first fruits of the new large scale employment, and they constituted a problem which caused worry on all sides.

The other great development of the period, but one which was not to be at first so noticeable, was the creation of scientific management. The system which now bears this name started as the personal reaction of the late Dr. Frederick Winslow Taylor to the above described labor spirit. Taylor was born of upper-class American stock five years before the outbreak of the Civil War. As a boy he had been educated in France, Germany, and Italy, and prepared to enter Harvard. Trouble with his eyes, however, prevented his continuance in college, and we find him during four years of his youth working out apprenticeships in a small Philadelphia shop as a pattern maker and machinist. He entered one of the new large scale establishments, the Midvale Steel Company, as a laborer in 1878. From laborer he successively rose through the positions of clerk, journeyman machinist, gang boss,

foreman, and chief draughtsman until he finally became chief engineer. It was when he became gang boss in 1880 that Taylor first determined to discover by scientific methods how long it should take a man to do each given piece of work; and it was in the fall of 1882, shortly after he had been elevated to the position of foreman, that he started to put the first features of scientific management into operation.

Before proceeding to an analysis of the principles of scientific management, let us first perfect our idea of Taylor by noting the other outstanding features of his life. In 1889, Taylor left the Midvale Steel Company in order to apply his ideas in a wider field. For three years he served a corporation operating large pulp mills in Maine, and then he attempted in various parts of the country a reorganization of industrial plants. This involved a variety of manufacturing, structural, and engineering work. His most celebrated personal undertakings were in connection with the plant of the Bethlehem Steel Company between 1898 and 1901. By 1901, Taylor had acquired a fortune which enabled him to retire from work for pay.

Dr. Taylor took the degree of mechanical engineer from Stevens Institute of Technology in 1883. In 1906, he served as President of the American Society of Mechanical Engineers. Besides his writings on management, he contributed to this society several notable papers on mechanical subjects, of which the greatest was his president's address in 1906 on the Art of Cutting Metals. He took out about one hundred patents, his greatest invention being the discovery between 1898 and 1900, jointly with Mr. Maunsel White, of the Taylor-White high-speed steel. He was honored by the University of Pennsylvania with the degree of Doctor of Science in 1906, and was claimed as a friend by some of the highest officers of the navy, and by prominent engineers, manufacturers, and public men. Dr. Taylor died March 21, 1915.

To return now to the youthful Taylor of 1880, and his beginnings of scientific management. Taylor's observation had been that his neighbors in the Midvale shops failed to produce more than about one-third of a good day's work. Wages were on a piece-work basis, and the men were afraid to let the management guess how large a product they could really turn out because it might mean a cut. This tendency on the part of the workmen had resulted in a war between Taylor, the gang-boss, who was trying to induce the men to work faster, and the workmen under him, who were determined that by fair means or foul they would avoid working faster. As a result of

this struggle, life to Taylor had become hardly worth living. Accordingly, shortly after he was given the greater authority of foreman, he determined to work out some system of management by which the interests of the workmen and of the management would be made the same.

The basic principle of the scientific management which he evolved is that the management shall determine very carefully just how much work a man ought to do, and, on the other hand, that the man should be offered a premium sufficient to induce him to perform the task. From this simple idea all of scientific management has grown, and to this idea most of it may still be reduced. The classic illustration of the scientific determination of the task was Taylor's twenty-six year study in the field of cutting metals. The regular method is to make a study of every element entering into a job; and then add together the times which it takes to perform the necessary elements, to find the time required to perform the entire job. A margin of safety is ordinarily left, to cover delays. The stop watch is the instrument ordinarily used in making the time studies.

The methods by which men are induced to perform the task are Taylor's differential rate— and, among later developments, Gantt's task and bonus system, and other special bonus or premium systems. The amount of reward to the workmen varies considerably, but most often amounts to twenty or thirty per cent higher wages than they have been accustomed to earn. Such a reward is usually sufficient to induce workmen to attain the tasks laid out for them; and the tasks can often be so set as to increase production one hundred per cent or more.

It is not to be supposed, however, that scientific management is based upon the overspeeding of workmen. The goal is reached largely through a more perfect utilization of machinery and tools, the elimination of actual idleness or wasted motions on the part of the men, the withdrawal from a job of operations that can more fittingly be performed some place else, and only to a very limited extent by means of speeding up. It is primarily the interest, the loyalty, the obedience of workmen that scientific management strives for; and for this obedience the management does not hesitate to pay a substantial price.

This method of inducing workmen to do their best constitutes, histroically, the most fundamental and essential aspect of scientific management. It is, however, by no means the system's only feature. It was very early discovered that in order to set tasks properly the management had to learn a great deal about the work, and, when it

knew a great deal about the work it could commonly introduce improved methods of performing it. So planning rooms developed, motion studies were made, instruction cards drawn up, employees trained, tools and equipment standarized at high quality. Much of the increased output under scientific management springs from the methodical and exact way in which these features have been worked out. This second story of scientific management is to-day almost as important as the first.

A third notable characteristic of scientific management is what is known as functional foremanship. In order that the management might discharge creditably its greatly increased responsibility, it became necessary not only to increase its numerical strength, but to split up the duties of management among as many as eight different authorities. These are given such names as gang-boss, speed-boss, inspector, repair-boss, order of work or route clerk, instruction card clerk, time and cost clerk, and shop disciplinarian.

A capacity in scientific management and its leaders to expand Taylor's original program and adjust itself to the needs of industry appeared very early. As the system was first thought out and practiced by Dr. Taylor, it had a certain inflexibility amounting almost to impracticability. And especially was this true of the methods which he used in pushing the system. It is no secret that Dr. Taylor was not himself very much of a manager. Persistence and genius he had without end. But he was not an adept at judging men, nor tactful or conciliatory in his method of approach. Even for his friends he was a hard taskmaster, and his entrance into a new plant would stir things up from the bottom. He insisted, too, that reorganization be thoroughgoing and complete, according to what often seemed a preconceived notion.

These characteristics were partly due, doubtless, to the fact that Dr. Taylor himself had comparatively little experience with the introduction of his own system. Besides his deep interest in scientific management, Taylor gave a considerable portion of his time to other matters. He was an inventor of no mean ability, and took much pains with scientific investigations, as, for instance, that into the cutting of metals. Taylor did not work what most men would regard as a full day, but came late and went home early. And finally, he retired from active service in 1901, at the age of forty-five, fourteen years before his death, and scarcely twenty years after getting started seriously in work. No wonder that he did not accomplish everything, and that much was left to be developed by others.

Among the first friends of Taylor to improve upon his methods was Henry L. Gantt. Gantt is what Taylor never was—a skillful manager. He has carried through such undertakings as the reorganization of the Union Typewriter Company, the concern which makes Remington, Monarch, and Smith-Premier typewriters, the Westinghouse Electric Company, and many other concerns almost equally large and well known. Gantt gets along well with the people whom he has to manage, bends his course to suit the exigencies of a situation, and aims at important practical savings. He regards every factory as a law unto itself. His scientific management is not one mould, which all factory organizations must be warped to fit; but, as he sees it, there are as many distinct scientific managements as there are different shops. Gantt's work, however, is only one illustration of what has been done to a greater or less degree by all the close friends and followers of Taylor. Scientific management is the joint product of many minds, working under the inspiration of a dominant personality.

The results obtained under scientific management have been such as to attract the attention of a wide public, and to win support in many and important quarters. As before indicated, it seems probable that on many kinds of work, the increased output of employees runs well up to one hundred per cent; while there are instances of increases of two hundred per cent and more. In other instances, of course, the gains are much more moderate. The prestige of the system among engineers and with the public has been heightened by the support of men like Henry R. Towne, James M. Dodge, and Frederick W. Taylor all past presidents of the American Society of Mechanical Engineers, and Louis D. Brandeis, Justice of Supreme Court; and by the space given to dicussions of the system in leading technical and popular journals and in the writings of leading thinkers. Its standing in the manufacturing world has been assured by its adoption in such representative plants as those of the Pullman Company, the Westinghouse Electric Company, the Yale and Towne Manufacturing Company, the Union Typewriter Company, the Remington Arms Company, the Goverment arsenals, and, in the old days, the Bethlehem Steel Company and the Santa Fe Railway. Some tens of thousands of workmen are already working under it in a fairly complete form; while it is safe to say that the influence of the system has spread in one way or another into almost all the industrial plants of the country.

In spite of this rapid growth in favor, there nevertheless remain some very powerful and persistent antagonists. When Charles M. Schwab obtained control of the Bethlehem Steel Company in 1901,

this company's position as a center of scientific management activity which up to that had been without a parallel, was promptly destroyed. While much of the system was in fact retained, all allegiance to it was emphatically disowned. It is not surprising that in this and numerous other places scientific management has met with opposition on the part of employers. The idea of one man does not take precedence over the ideas of a thousand other men without meeting constant challenge, especially when it is the province of the other thousand to decide the issue.

The only opposition which may be regarded as really serious, however, is the opposition of organized labor. The reports of the American Federation of Labor show that their first period of rapid growth occurred following 1898 and prior to 1904. In these years the membership of the Federation leaped by one great bound from 275,000 in 1898 to 1,675,000 in 1904. But following 1904, for a period of five years the Federation lost ground, so that in 1909 the membership was about one-ninth less than it had been in 1904. This check seems to have been imposed partly by a hostile attitude assumed by the courts, but more especially by a policy of antagonism on the part of great corporations and powerful employers' associations. Professor Commons, writing in 1908, declared that "the unions have practically dissappeared from the trusts, and are disappearing from the large corporations as they grow large enough to specialize minutely their labor."[1] Naturally the unions began to give their attention to the matter of the obstructive forces, and to form plans for defending themselves. In the words of Professor Carleton, writing in 1910-11, "bitter opposition and adverse judicial decisions may force even conservative unions to adopt other methods and policies than those utilized during the last two or three decades."[2]

1. American Journal of Sociology, vol. 13, p. 759

2. History and Problems of Organized Labor, p.75

It was just at this juncture that for the first time a blaze of publicity was thrown around scientific management. In the fall of 1910 and the spring of 1911, the now Justice Brandeis conducted before the Interstate Commerce Commission his famous defence of the eastern shippers against a proposed advance of railroad rates. Brandeis' main argument was that the railroads would not need to increase rates if they would introduce scientific management. In a few weeks,the entire country was inquiring as to what this scientific management was,

and organized labor was confronted by the necessity of taking a stand with reference to the new development.

The labor leaders very quickly and very properly decided that the growth of scientific management presented a danger to their organization. The main reason why we have labor unions as at present organized is because of the existence of laboring classes, whose manner of life, education, and interests are enough at variance with those of the employing classes, so that the former crave a special protection. Were there no sharp divergence of interest or sympathy, it would not be necessary to build up class solidarity, to insist on organized action, or to extend systematic aid and protection to the otherwise isolated worker.

It was, however, a postulate laid down by Dr. Taylor that there is no natural clash between employer and employee. Both, he would say are interested primarily in greater production. Taylor believed that he had devised a system that would substitute a scientific for a contentious division of the product. Employers should not be organized in employers' associations and workmen in labor organizations for the purpose of battle. But all should be partners, work in harmony, and settle their relationships according to scientific truth. Recognizing no divergence of interest, Taylor, therefore, would have the management itself look out for the laboring man.

To Taylor and his followers, moreover, the spirit of the unions seemed unfavorable to industrial progress. Taylor was interested in greater production, in introducing better methods, in progress; whereas the union membership is made up largely of that middle class of people who are conservative, suspicious of change, and somewhat hard to reason with. In particular, the workingman has been suspicous of the introduction of machinery, of increase in output, of speeding up. Partly just, partly unjust, these suspicions have been; but they were a big factor in preventing Taylor and the unions from working as partners in a common cause.

The outcome in scientific management plants of this unfavorable sentiment towards trade unions has been that the latter have almost invariably had the worst of it. Taylor testified before the Industrial Relations Commision in 1914 that members of labor unions had left in large numbers at Midvale, Bethlehem, Tabor, Link-Belt, and to a certain extent in every company where he had ever been. It is easy to see why unions could not put up much of a fight in shops operating under such a system. In so far as it centralizes skill, scientific management takes from the workman that bond of common craft knowl-

edge, which tends to make brothers of the men engaged in a trade. Since it pays on an individual or efficiency basis, and promotes the more able men to fill positions as functional foreman, scientific management appeals to personal ambition, rather than class solidarity and makes less sharp the line of cleavage between management and men. As it voluntarily pays higher wages than the men could win through force, scientific management weakens the main motive for organization, and makes the employees hesitate to compromise themselves with their employers. In short, scientific management did not need to lay itself out to any noticeable extent in order practically to rid itself of trade union connection.

Scientific management was not extensive enough in 1904-1909 to have been any important factor in the temporary checking of trade unionism which then occurred. Its spirit, however, was one with the spirit of the great corporations which were making themselves independent of unions. Its spirit was the very essence of centralized power, of managerial self-sufficiency, of workingman subordination. Against its winning persuasiveness the outside labor union could hurl itself in vain.

It was not to the workingman, however, that organized labor was to make its appeal. A million or two men are not sufficient to control the industrial world. But a million or two voters are not to be neglected. It was in the political arena, therefore, that organized labor was to show its greatest strength; and it was to Congress that labor went for aid in its contention with scientific management.

Congress happened to have a very direct concern in scientific management, inasmuch as the system was being introduced in the government arsenals, and was later to be proposed for other departments,—as the post office. On its floor, therefore, ever since 1911, bills and resolutions in great number have been introduced calling for investigations or prohibiting the continuance of the system. In particular, riders attached to appropriation bills have proposed to withold funds for the making of time studies or the payment of bonuses.

The first victory for labor was won in March, 1915, when the House forced the Senate's unwilling consent to provisions in both the army and navy appropriation bills forbidding the use of funds for either of the purposes just mentioned. The shaft failed to hit the mark, though, as it developed that the condemned devices were financed through the fortifications appropriation, and not through the army or navy appropriations. In the 1915-16 session of Congress the fight was therefore taken up again with renewed vigor, and riders

withholding funds for time studies and bonuses were attached to the fortification, army, navy, post office, and sundry civil appropriation bills. All these measures went into operation last July, and had the important effect of suspending bonus payments at the Watertown Arsenal, the one point where the Government had extensively introduced scientific management, and also preventing, for the year at least, the installation of scientific management in the other branches of the federal service covered by the bills. A yet more substantial victory, however, is the goal of labor. The Tavenner Bill, introduced and fought over last session, and on the calendar for consideration next session, would permanently forbid by statute the use of time-measuring devices on, or the payment of bonuses to, any employee of the United States Government, declaring any such act a misdemeanor punishable by fine or imprisonment. The VanDyke Bill, which now rests in the hands of the Committee on Post Offices and Post Roads, contains similar provisions, but applies to the post office only.

Such tactics on the part of the labor men, and the response being made by Congress, seem to be, and, we believe, are, both unjust and a menace to the future progress of the country. Yet it is not hard to see how the situation arose; nor is it impossible to find weaknesses in scientific management itself which invited such attack. It is true that the arguments presented to Congress were pitifully weak. The two counts against scientific management are first that it involves overwork; and second, that to have one's motions timed by a stop watch is degrading. But neither government commission nor critical private investigator has been able to unearth any extended instances of overwork. Even so watchful a critic as the late Professor Hoxie testified that he had "a strong impression that scientific management workers, in general, are not overspeeded."[1] And as for the stop watch, the real objection, surely, cannot be to the thing itself; but only to some peril that it is felt will grow out of it. But what this peril is, is usually not very clearly indicated.

Yet underneath these surface arguments, there exists a real clash involving fundamental principles. We are called to witness a struggle, which it would be folly to try to evade, and which is bound to continue until both scientific management itself, and the general character of our national life will have been profoundly affected. Taylor himself never regarded scientific management as perfect or complete. We may, therefore, without prejudice to him, or his work, inquire into those aspects of his system which are at the real root of the present

controversy, and which the world of to-morrow probably will not accept, save in modified form.

In the first place, and of most importance, the confidence which the system places in the unselfishness and public spirit of the management is excessive. Not that managements may not, and have not, in notable instances, possessed great virtue. But there is no reason to suppose that those particular organizations known as industrial corporations can be made so universally and fundamentally superior to city councils, labor unions, churches, chambers of commerce, *etc.*, that they alone of all organizations should be allowed to go their way unchecked, unwatched, possessing the complete and unchallenged confidence of the public, of labor, of the government. Taylor was eminently right in urging managements to assume this high character; and one of the most hopeful signs of the time is the noble way in which they have responded. But should not the pre-eminence which any management enjoys in this respect rest upon the voluntary recognition of its achievements and character, rather than upon a pious insistence that organizations of employees or of outsiders must refrain from passing an opinion upon matters so out of their sphere? That would not be a popular attitude if assumed by the president of the United States. Even a bank cashier, though selected for his integrity, does not refuse to have his accounts examined.

1 Scientific Management and Labor, P. 92.

In the second place, the principle of Dr. Taylor that the management should acquire and sum up in itself *all* the skill and science required in industry is an ideal that is likely to fall increasingly short of realization. In no shop has scientific management yet succeeded in placing *all* of the work on the task basis, though sometimes this end is fairly closely approached. Not even in the best and most widely praised shops is the time allowed for the work so scientifically correct, that all jobs are equally exacting, and that the men take no thought of limiting their output a little on the easier jobs. Yet time study based on existing methods is the least serious of the tasks which scientific management has obligated itself to accomplish. How likely, then, is it that when it comes to devising entirely new methods of work, the small group of men in a shop known as the management will be able themselves to hit upon all of the best features. As industry increases in complexity, and as the laboring man grows in education and intelligence, we may be sure that a time will come when the

laboring man will know more about many things than the management possibly can. Hence this system's vision of an industry animated almost altogether from the top may turn out to be considerably distorted.

In the third place, scientific managemement has relied too largely upon the daily wage as an all-powerful link binding a man with ties of loyalty to his employer. Pay is undoubtedly the one most important relationship that needs careful treatment in order to insure the loyalty of employees. But it is by no means the only factor. Much of the best work of the world in science, in government, in art has been done for small pay. Even in business the British man of affairs is apt to be as much influenced by the hope of a peerage, as by that of large profits; the American financeer as much by the love of playing the game as by the pleasure of disposing of the proceeds. It is to be hoped, therefore that managers may acquire greater skill in analyzing human motives, and be able to control various additional forces that lead men to labor.

In the fourth place, scientific management has given only superficial attention to the important topic of fatigue.

There is a widespread impression that, in addition to what has already been noted, scientific management has been yet more careless in its estimate of the worth of workman; that it has ignored much of their humanity, and consciously and inexcusably been indifferent to their welfare. There is much gross exaggeration in this. Dr. Taylor once declared: "The interest of every man who is in anyway engaged in scientific management, in the introduction of the principles of scientific management must be first the welfare of the working man. That must be the object. It is inconceivable that a man should devote his time and his life to this sort of thing for the sake of making more money for a whole lot of manufacturers." As far as Dr. Taylor's own actions were concerned, his life put the stamp of sincerity upon these words. And it is equally true of most of the other men active in introducing scientific management that they have been kindly and even magnanimously disposed towards labor.

Yet, as Mr. Robert G. Valentine has well said, many of the impressions which Taylor conveyed in discribing his ideas did violence to his real spirit. He used to speak, for instance, of pig-iron handlers at Bethlehem as having the mentality of the ox; and designate whole classes of workmen as being analogous to the dray horse, or the grocery-wagon horse; while others were of the trotter class. Such language did Dr. Taylor and his cause immeasurable harm. Yet he had

no thought of insult. In later life he would in like manner swear before classes at Harvard; though probably he had genuine respect both for the institution and the students. It was merely his picturesque and forceful mode of expression, schooled as he was in the ways of the shop.

Possibly, however, it should be put down as one of the weaknesses of scientific management that it takes workmen too much as they are, forgetting that a larger social program might conceivably make of them quite different and better men.

While we therefore believe that certain aspects of scientific management are not ideal, this is not to be regarded as an adverse criticism of Dr. Taylor, or his work. If only we recall the conditions under which scientific management was originated, we are compelled to forgive and even praise the course which Taylor followed.

Take workmen as Taylor knew them about 1880, and a paternalistic system was eminently fitting. Strangers in a new country, ignorant of its institutions, crude and stolid in intellectual development, they were not fit for self government. The employers of this time, moreover, had to fill a more responsible and independent position in the nation's industry than ever before or since. It was in the initial stages of a new and large-scale production, when resources were being exploited, new fields of manufacture opened up, foreign markets conquered. In such a period of transition and construction, the business enterpriser is the all-important director of the country's activities. Even able employees have little higher responsibility. The great questions to be decided are whether an industry should be created, or perhaps discontinued; whether the people employed should be skilled or unskilled, or whether machinery should displace labor. On such matters the employees concerned cannot, of course, pass unbiased judgment. What industry needed was a pliable working class, who would fit in readily with the shifting programs of capitalist and enterpriser. Lucky the workman who could secure a benevolent employer. And lucky the manufacturer who could secure humble, foreign workmen, unbound by tradition, and not self-assertive.

Likewise, when we remember Taylor's situation, we cannot blame him for refusing to allow much place for the initiative of workmen. Many of the workmen were of the class just described; and most of the balance lacked that specific training which might otherwise have made their co-operation of value. The graduates of the new engineering education were in the eighties but a thin leaven in a great world; while it was to be many years before the schools were to plan an in-

dustrial education for the masses. But even had they been trained, the workmen of Taylor's time were filled with a suspicion of efficiency that made them more interested in limiting output than in increasing it, in blocking the introduction of machinery and improved methods rather than in assisting in this work. These conditions, we believe, account for and excuse the rigid control, the too sharp separation of planning from performing, and the insistence upon a rather blind obedience to directions which has characterized scientific management.

Again, the earlier relations which had prevailed between employers and employees may be cited as an explanation of Taylor's failure to develop any thoroughly socialized system of drawing out loyalty. Scientific management was started in order to displace a warfare which had developed between management and men. And in combating and overcoming this warfare, the system necessarily took a part of its own character from it. The spirit of the men had so long been steeped in antagonism, that there was practically only one appeal that could be made to them. The central principle in the science of management therefore became the forging of a very tight and somewhat mechanical grip upon employees, through a skillful regulation of their pay. It is, however, to the great credit of Taylor and his associates that they progressively gave more and more attention to the spirit of the shop, and dwelt less heavily upon the earlier mechanical devices.

This justification, which we have just been making, of the attitudes assumed by scientific management in times past, does not however, affect our judgment that, in the future, a more democratic control and a more widely diffused responsibility will have to prevail. Certain basic changes now taking place in our social and economic institutions will eventually render obsolete many practices once thought necessary.

The chief of these changes, and the one which will have the greatest import for scientific management, will be a transformation in the working population. Any group of people who presume to outline a program for the future which does not take into account the rise of an employee class quite different in character from that which formerly filled our shops will be making a grave mistake. The whole trend of our modern spirit is in the direction of a sharp uplift of the mass of mankind. Our original human nature is going to blossom into a very different kind of manhood and womanhood under the greater opportunities which are now being thrown open.

The accomplishment of such a transformation is the goal of the progressive political movement, which gave up its independent life only because it had won control of one, if not both, political parties. The elevation of the ordinary man is the program of the modern social movement,—which dominates the public schools, the churches, the universities, and the Y. M. C. A., and finds its expression throughout the literature of the time. It is this spirit which has borne fruit in the reform of taxation, in the fight against privilege, in the founding of all sorts of civic institutions, but first and preëminently in the expansion of popular education.

We must think of the employee of tomorrow, then, as the graduate of a technical or trade school, if not of a university. We must think of him as a man or woman of culture, of intellectual power, of initiative, a person nourished from youth in the exercise of freedom and judgment. Trained in science, and polished by a varied experience, he will be no more like Taylor's pig-iron handlers, or the typical workman of yesterday than vapor is like a solid or a liquid. In short, the human material with which the science of management purports to deal will have been changed. And when the subject matter of a science changes so must the science also.

In keeping with this new environment, we must therefore anticipate a new scientific management. It will have to be somewhat different, first of all, in method. The ideal of securing individual efficiency through restraint and command will have to give way some time, before the more efficient program of opening the way for individual self expression. Not that no one should lay out tasks for others; or that vast numbers of workers should not make their methods conform closely to one most efficient standard. An opera singer may fittingly follow the directions of her managers as to routes of travel and concert dates; a great engineer or builder may conform in detail to specifications drawn up by others. The point is that, while an individual does many things that others plan, he should have some things to plan himself. That is what a man is for. To neglect to utilize and develop the unique originating, choosing, and adapting power with which every individual is more or less endowed is to waste the earth's greatest resource, a resource for which the growing complexity of industry and the arts will ever make greater demands. Besides, to deprive men of the opportunity to create is inhuman, degrading, and destructive for the individual, the ruination of pleasure in work, of romance and achievement in life.

Scientific management will also have to clothe itself in a somewhat different spirit. That age-long impulse towards democracy that first humbled kings, and later liberated and enfranchised serfs, is still in full swing; and can stop short of nothing but complete social and individual emancipation. The storm that has risen around scientific management has largely grown out of a notion that the system was trying to block this movement. But we need not fear that such an interpretation of the system can be maintained. The age that rushes to give the vote to women on this side of the water, and hesitates in time of national peril to conscript labor on the other side will not tolerate any system of management which does not give praise to the man who works, thrust upon him respect and opportunity, give heed to his sentiments, acknowledge his fellowship, ask for his co-öperation. Whatever smacks of any other feeling in scientific management is a product of the past, and like it will have to be left behind.

The fathers of our revolutionary period, it is worth while to remember, were not greatly injured by the policies of Great Britain. For years after the revolution they continued to buy mostly from England, and to use much the same trade routes as it had been the policy of the mother country to prescribe. Their burden of taxation was only increased by independence, their protection diminished. But the founders of our nation would not tolerate the shadow of subordination to Great Britain. It was the spirit rather than the acts of the imperial government which inflamed American opinion and led to the longest and most fateful struggle in our history. So let us take heed of the continuation of independent spirit among the masses, even the immigrant masses of to-day. Let us be thankful that the spirit of our country's past is not dead, and let us bend before it, work with it, utilize it. Not money alone, but self-respect, responsibility, partnership, is the birthright of American labor. Not only the reality of these things, but out and out, thoroughgoing recognition must be maintained.

Now these things have not been overlooked altogether by Dr. Taylor's associates. The most interesting development in the field of scientific management at present is the start that is being made in the direction of such Twentieth Century ideals. The recognition of the humanity of employees, of the importance of the social life of an industrial organization, is possibly nowhere more complete than in the Clothcraft Shops of the Joseph & Feiss Company, Cleveland. In a paper on Personal Relationship as a Basis of Scientific Management, written by Richard A. Feiss, the manager, as well as in various des-

criptions of the Clothcraft Shops given by other persons, it would appear that we have here an unusual example of a socialized industrial undertaking. Among the institutions of the factory are a choral club, with membership upwards of two hundred, a factory orchestra, and leagues for baseball, quoits, captain ball, and other sports. During the winter, the different divisions of the shops give parties, at which entertainment is furnished by the employees and their families Members of the firm, as well as all others, attend these parties, and a democratic spirit prevails. On regular days dancing is a feature in the women's recreation room, and there are dining rooms where every employee has his own seat.

One of the the highest officials of the Joseph & Feiss Company is their Employment and Service Director. It is, among other things, the duty of this lady and her department to develop an organization spirit, and to facilitate among the employees the development of a democratic expression of personal and public opinion. The department itself comes in contact every day with about one-fifth of the Clothcraft employees; and all cases where direct conference with the management would be beneficial are immediately referred to it. The interest of the firm in its employees extends also to their families and their homes, the Employment and Service Department having instituted the practice of home calls. One effect of these visits and of the company's careful medical advice has been the practical elimination of tuberculosis. A net effect of the entire social and individual program has been the development of an *esprit de corps* which has been remarked by all observers.

The road to advancement in these shops, moreover, is not only open to all employees; but every possible aid and encouragement is given. Practically all positions in the organization, both clerical and executive, are filled by those whose abilities have raised them from the ranks. The plant has reading rooms and a branch of the city public library. Information is furnished employees concerning special classes in the schools. The management believes in encouraging to the utmost individual education and development.

The significant thing about the Clothcraft Shops, however, is not these things taken by themselves, but the fact that the shops are operated under scientific management, the features described being regarded not only as consistent with, but essential to, a thoroughgoing application of Taylor's principles.

Another plant widely regarded as characterized by an advanced spirit in the place accorded to the men, and also for many years in sym-

pathy with the Taylor movement, is the German-American Button Company, of Rochester, headed by Mr. Henry T. Noyes. Mr. Noyes has a wide vision of the change in spirit that is taking place in industry, and regards the old way as a survival of feudalistic class distinctions. In particular, the distinction between office and factory is a relic of the old disdain with which a leisure class formerly regarded the laboring class. Conditions as to hours of work, and treatment in the German-American Button Company are identical for office and factory. Even in ringing in and out on coming to and leaving work, officers, office, and factory have followed the same routine.

Mr. Noyes counts on his employees taking a part in the life of the business through regular department and other meetings. Practically all the foremen have risen from the ranks. None of these features are found to be inconsistent with the use of the stop watch. Nor has the latter device prevented the development of the most cordial relations between management and men. Even the Italians of the second generation are welcomed into the fellowship as full Americans.

These illustrations are advanced not because the shops described are necessarily superior to anything that might be reviewed outside of scientific management; but because the honor and attention which great numbers of the followers of Taylor are giving to this kind of thing shows in which direction the tide of scientific management is setting. We do not say that the spirit in these shops is perfect, or that they are an exact prototype of what will later be universal. On the contrary, we are very doubtful about some of their policies. But do they not in fact show that scientific management is striding towards a more humanized and socialized system, a real science of human relations?

The last point which we wish to make is the important one that, in spite of any elements in scientific management which the future may show to have been ephemeral, there is in the original spirit of Taylor a principle or two that is valid not only for his time but for all time. The changes taking place and to take place in the outer aspects of scientific management have not and will not carry it away from these principles. They may be given as two in number: first, science in industry; and second, harmony in industrial relations.

The science at which Dr. Taylor so skillfully worked was, as he himself used to insist, never complete. With every change in social institutions, the human side of it will have to be recast; with every

advance in invention and industrial technique, the mechanical side of it will tend to become obsolete. Yet the vision of a science in industry has taken possession of some dozen of the leaders of American industry, and by them is being passed on to numerous factories, until it is to be hoped that it will reach ultimately the humblest of American workingmen.

The harmony which Dr. Taylor tried to establish ignored several important forces, which his training had not permitted him to understand. His quest for harmony led through conflict, passion, and disappointment to death itself. Yet Taylor's vision will not be forgotten, nor will the effect of his effort be lost. In many factories the relations between employers and men have been ameliorated. And his ideal to consolidate and unify the conduct of American business will live.

Mr. George D. Babcock has defined scientific management as "that kind of management which conducts a business or affairs by standards established by fact or truths gained through systematic observation, experiment, or reasoning." Concretely put, this involves, first, the scientific laying out of tasks; second, a just system of rewards for those who successfully coöperate; third, the scientific study of methods; and fourth, the organization of all work according to a functionalized or specialized division of authority. The more one reflects over these principles, the more evident it becomes that the industry of the future will have to be built upon some such general basis.

It will be the task of human engineering to see that the standards set up under scientific management become increasingly more scientific, taking into account the real natures of both materials and men. It will be the task of public opinion to see that industry becomes progressively more vitalized and more democratic.

SOME COMMENTS ON THE CONGRESS

"Those meetings at Ohio State University on the subject of Human Engineering, placed before the students the question of the handling and caring for men from many points of view. It must have stimulated their thoughts for they showed a live interest. The question is now a pressing one and apt to become acute."—Willard Beahan, New York Central Lines.

"The presence together on the same platform of representatives of labor and capital, and of organizations striving to make the relations between capital and labor more friendly, must have impressed all those who attended the Congress with the importance of the human element in industry. In addition, the addresses themselves were so practical and sane that no hearer could fail to be impressed."—L. T. Warner, Warner Brothers Company.

"The Congress of Human Engineering held in Columbus stimulated two thousand young men who face the realities of the industrial world. They heard from men actually engaged in the industries a discussion of problems, experiences, and results which have years of practice back of them. These are criteria which will be of inestimable value to them when they enter the industrial world."—Peter Roberts, International Committee of Y. M. C. A.

The Ohio State University is the first educational institution which has taken practical action in calling attention to the growing importance of Human Engineering. In bringing together for a three day's session representative engineers, educators, students, and responsible executives in the trade-union movement, The Ohio State University was able to secure the broadest discussion of the problem from its several angles.

As one result, the importance of the problem was emphasized more than ever before, definite form was given to what previously had been hazy outlines, and a program outlined which other universities will undoubtedly follow.

The State of Ohio is to be congratulated upon having a State University possessed of the initiative, the understanding, and the farsightness, to provide for such a Congress as the recent one on Human Engineering."—John Frey, Editor International Molders Journal.

The results are bound to be of great value, especially in bringing before your engineering students the facts as to the great prog-

ress being made throughout the country in the matter of social betterment. I am sure that the young men who attended this conference now have a new conception of the value of the human factor in industry."—C. J. Hicks, Colorado Fuel and Iron Co.

"Engineers are fast awakening to the fact that there can be no real efficiency in production without willing co-operation on the part of workmen. The Congress not only emphasized this view but pointed the way by which such co-operation is to be secured."—W. A. Knight, Professor of Machine-Shop Practice, Ohio State University.

"I feel that it has been profitable for me and it must have been even more so for the students who are only just beginning to think along these lines. I believe that the idea has great possibilities for all of the large colleges in the country. It gives to the students a very necessary element in education which cannot be obtained from text books—an element which enters very largely into efficient management and one that students heretofore have been entirely lacking in. As a means of clarifying our vision along these lines and as an inspiration, future congresses should prove invaluable. By all means go ahead and push the idea."—W. B. Chapman, Chapman Engineering Co.

"I am thoroughly convinced that the "Human Engineering Congress" marks a new epoch in engineering education. With over 2,000 students, 200 business men and special visitors, I am sure that the Congress made a profound impression—not only on the University but upon all representatives of other interests. Every speech was splendid, and although the speakers represented many points of view —employers, engineers, labor leaders, Y. M. C. A. secretaries, etc.—they all dwelt on the importance of a larger appreciation of the human side of engineering, wider knowledge of industrial and social problems, and a greater ability to handle men intelligently and sympathetically.

When so much curriculum study is given purely to technical subjects, it was a strategic move to focus the attention of the engineering and other students on the human side of their profession."—Fred H. Rindge, Jr., International Committee of Y. M. C. A.

"The idea of the Congress of Human Engineering was capital and the execution of the project was a real contribution to present day education and manufacture.

Our greatest problem is undoubtedly manhood and womanhood in industry. Our colleges and our college men must contribute largely to its solution or lose their place in the life of to-day. The

engineer is particularly important in the execution of any plans of industrial betterment.

The idea of the Congress should be made permanent through proper courses of study in our universities and through similar Congresses in other institutions. As an Ohioan, I am particularly glad that our own State University should start the ball rolling for so much good."—E. L. Shuey, Lowe Brothers Company.

"If I sensed the spirit of this Congress correctly, its conclusions may be summed up in the one statement: that the narrow, technical engineer is the engineer of the past; that the engineer of the future will be one with a more thorough training in the fundamentals, with a knowledge of men and things, and a sympathy broad enough to see even in the most illiterate immigrant not only a human being but a future American citizen."—C. C. Morris, Assistant Professor of Mathematics, Ohio State University.

"There is no doubt that more work of this kind ought to be done among engineering students who will naturally, later on, be placed in positions of leadership in industry, furthermore the manufacturers and employers of labor as well as labor leaders and laboring men should be brought into touch with each other more frequently in meetings of this kind. The papers and addresses given were from thoughtful men who have made more than ordinary progress in matters concerning the vital relations between employer and employee and if other "Congresses" are held more effort should be put forth to secure an attendance of those now engaged in industry who need education along these lines."—John C. Haswell, The Dayton Malleable Iron Company.

"The Ohio State University deserves the highest credit for having the courage to call the Congress of Human Engineering. You have hold of a structural idea that is most timely. I do not believe that the most sanguine can forecast the formative influences which such a Congress will exert in mediating the interests of labor and capital and in planting a right spirit in student engineers as regards the human factor in industry."—Samuel C. Mitchell, President of Delaware College.

"The Congress marked a notable advance in the progress of Human Engineering. The successful program and the presence of 1500 engineering students besides leaders of industry (both employers and employees) were striking features. The fact that the University of Ohio called such a meeting is most significant and I hope the example

will be followed by other universities."—Chas. R. Towson, International Committee of the Y. M. C. A.

"In my estimation the meeting was a decided success and an excellent beginning of a movement which I should like to see continue and expand. I know of no better way to find a solution to our great industrial problem than by bringing together for frank and free discussion the executive of industry, the labor leader, the community welfare worker, the students of new theories of Human Engineering and the young man who contemplates some industrial pursuit. Such gatherings as the Congress at Columbus promise much in bringing about a realization of the importance of the human element in industry."—W. D. Gilliland, The Selby Shoe Company.

"Throughout the entire series of meetings, I noted the very serious consideration on the part of the audience, which was made up largely of students, of the human side of the Engineering profession. Probably the boys will remember very little of the details of the information which was handed out to them, but I am sure you succeeded in giving them a lasting impression that Engineering is not altogether mathematics, and that human interest is not altogether sentimental. There is no question but that a first class business efficiency and the highest grade of human fellow consideration go hand in hand. I think you got this point across."—C. R. Dooley, The Westinghouse Electric and Manufacturing Co.

"It is indeed a most encouraging and hopeful sign to find a University which realizes that after a young man has secured all the book training and instruction which he is able to get in college, that in the last analysis his success depends upon his ability to apply the knowledge obtained through an understanding of human nature. Very little can be accomplished by any one individual in any industrial establishment entirely through his own efforts; it is his ability to obtain the co-operation of all those who work with him, and thereby give to them such knowledge from his own fund as will be of benefit, and secure from them that which it is necessary for him to have in order to be an efficient worker, foreman, superintendent, or manager, that really counts."—Charles R. Hook, Vice-President, American Rolling Mills Company.

"The Congress of Human Engineering held at The Ohio State University October 26, 27 and 28, in my opinion will redound to the good of mankind and especially those who are engaged in industry. The wide latitude and free expression on humanitarian problems that was allowed and indulged in by the different speakers and the discus-

sions that followed will have influence for bringing a better understanding between Capital and Labor relative to each other's rights and duties."—John A. Voll, President, The Ohio State Federation of Labor.

"The Congress of Human Engineering recently held under the direction of the Department of Engineering of Ohio State University, is an advanced step in education. No one could have listened to the practical ideas presented without being enthused with the possibilities of such an undertaking. The whole affair rang true. An honest purpose was evident. There was no attempt to deal with the impractical. The Congress was a success not only because the men back of it knew what they were about, but for that better and more enduring reason that the subject with which it dealt was intensely human and practical. The world is looking more and more to the trained engineer, and any agency that emphasizes the necessity of a broader understanding of the human factor, ought to have not only the sympathetic response of our industrial leaders and educators, but also their enthusiastic moral and financial support. Industry has long been waiting for some such instrumentality as the Congress of Human Engineering."—W. A. Grieves, Secretary, The Jeffrey Manufacturing Co.

"This achievement of bringing together so many eminent and representative men to discuss the human element in industry is worthy of the very highest praise and commendation, and it was indeed a privilege to have the opportunity of hearing and meeting them.

Being educated as an engineer, and for many years engaged in industry, I realize that engineering courses are narrow to the extent that they deal only with things and that to-day the human element in all industry is by far of paramount importance. I can think of nothing to make the engineer more valuable to society than a good grasp of the human questions."—S. P. Bush, President, The Buckeye Steel Castings Company.

"The movement initiated by the Congress of Human Engineering at Columbus is in line with the most important and far reaching efforts towards better things. It is founded upon the deepest lying principles governing human action and is designed to meet some of the greatest of our present industrial needs. Primarily it recognizes the fact that the full efficiency of any man, whether employer or employee is the outcome of good will, of the proper mental attitude, such as is attained only when men have a close personal sympathy and a feeling that each is entitled to and is receiving the best which the conditions afford. The movement appeals particularly to the young en-

gineer who is beginning to see that he, as a technically trained man, is to be at the focus of affairs where much depends upon him either to put oil or sand in the bearings.

The most striking fact developed by the Congress is that industrial or engineering success for any one man or class of men does not necessarily involve corresponding distress of other men; but rather the contrary. The highest rewards in business affairs can be and are being attained while the workers are being given an opportunity to live their own lives in the best possible way. This is by no means a new discovery made by the Congress of Human Engineering, but, while old as the knowledge of the Golden Rule, the fact was brought out with a freshness and vigor of presentation rivaling that of a new born idea.

It is not to be supposed that there was complete unity of opinion on all fundamentals discussed; the representatives of labor union of capitalistic or socialistic ideals were intense in their convictions, but through all difference as to method there ran the thread of optimism and of belief that it is possible to arrive finally at realization of higher ideals of life among the workers; also that this will come not from charity, but rather from a better conception of equity and fair dealing among men, made practical by business consideration, as well as by higher ideals. There was an appreciation that no working man desires to be considered as an object of charity but each has a proper right to demand equity. There was recognition of the fact that the employer may properly assume the attitude that "when a man's name is on our pay roll we should have him on our heart", not in a patronizing way but as arising from the demonstration that fairness in dealing alone will produce the best industrial conditions accompanied by ultimate profits."—F. H. Newell, Professor of Civil Engineering, University of Illinois.

The Congress was surely a move in the right direction. We do not care so much for expert efficiency as the term is usually understood but rather the thing that would give us a larger appreciation of the human element and enable responsible ones to care for and develop the individual by cultivating and developing a larger interest and out look, rather than a speeding up process.—W. H. Morrison, President, The Delaware Garment Company.

Those men and women who are honestly seeking to bring about industrial peace must have gotten a broader vision of their tasks and a greater faith in each other.—Constance MacCorkle, Secretary of the Industrial Committee of the Y. W. C. A.

You have started a movement in a direction very much in need of emphasis not only from the standpoint of such "wild-eyed" social workers as some of us are, but from the standpoint of the most hard headed engineers and employers of labor.—A. W. Bookwalter, General Secretary Cincinnati Y. M. C. A.

I was greatly impressed by what seemed to me the value of your Congress to the student body. The advantage to the students of such a meeting is that they may see the subject presented from all points of view by unbiassed observers. More and more colleges should be deductive rather than inductive. Too much stress in writings has been laid on the so-called "humanitarian" point of view before a careful investigation of facts.—W. P. White, General Manager, The Lowell Paper Tube Corporation

The Human element in any phase of progress is of vital importance. Co-operation and mutual understanding add to the sum total of happiness,—the goal of the designer, engineer, builder and workers. The meetings have emphasized a necessary thought for the young man striving for success, it may save him from the failure of his life and many sad experiences, for the man of experience is compelled sooner or later to recognize some form of mutual responsibility with and consideration of fellow workmen.—E. M. Fitz, Electrical Engineer, Pennsylvania Lines.

I believe that just such meetings as this will do much toward getting the engineer to thinking along the lines which will eventually solve the labor problems of the day. A. W. Kimmel, Dayton Engineering Laboratories Company.

The closer the employee and employer can be drawn together at the Plant and away from it, the better will be their appreciation of each other. The conference where all were welcome to discuss their problems was certainly sprung from an inspired idea and should result in great good. J. L. Junkin, LaBelle Iron Works.

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The Chemical Examination of Natural Brines

BY

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AND

JAMES R. WITHROW

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THE CHEMICAL EXAMINATION OF NATURAL BRINES[1]

By O. R. Sweeney and James R. Withrow

The proper analysis of natural brines has always been important. They are used by chemical manufacturers to make comparisons with a view to reaching decisions as to prospective yields of salt, bromine and other products. The war-time elevation of the price of bromine from 30 cents to as high as $6.50 per lb., as well as a similar elevation of other products derived from natural brine, has given rise to search for additional sources of these products and a careful scrutiny of many of the brines encountered in oil, gas and coal development, and hitherto wasted. As a result many analyses have been made in the last three years as a basis for manufacturing consideration. Some of these were made in the laboratories of manufacturers themselves and some by consulting chemists. Analyses from both sources have come into the hands of the authors as the basis for report upon prospective manufacturing values. We, also, have had occasion to make check or confirmatory analyses.

It early became evident that there was no standard or uniform procedure being followed by the different workers. To this fact may be due a large part of the non-agreement encountered from time to time, though inexperience with this type of analysis is also a factor. Few chemists, even water analysts, are experienced in such a type of work as bromine determination in brine. This may be shown best by citing a report to its president by the laboratory of the chemical company. The letter from the president of one chemical company to another stated:

"The analysis of the two samples of brine which you sent us has been completed and it was some job. The results are as follows:

	Well A	Well B
Depth	1200 ft.	1200 ft.
Diameter	8 in.	4 in.
Specific Gravity of Brine	1.071	1.070
CaO	0.69 per cent	0.68 per cent
Br	0.42	0.22
Halides (as sodium halide)	9.21	9.26
Iodine	None	None"

These samples were from a brine whose composition was well known to us. Furthermore, they were on

[1] Read before the Industrial Division, Kansas City Meeting of the American Chemical Society, April 12, 1917.

the same property. It will be noticed that they are of the same depth and also the same specific gravity, CaO content, and halide content. Nevertheless, they are reported of different bromine content—adivergence of nearly 100 per cent. Such a divergence would be a very important matter industrially, for one of these wells would give nearly twice the yield of bromine for the same turnover of salt and calcium chloride and at the same fuel cost as the other well. Considering the difficulty of bromine determination, by the usual methods, the infrequency of demand for it and the concordance of all other determinations on these two brines one is tempted to suspect the accuracy of the bromine determinations. As a matter of fact even the lower value is over twice the bromine content of the field in question as shown by both analyses by various chemists and experience of *all* the plants operating on this particular brine.

Such situations give rise to controversy and discredit analytical chemistry. An examination of the literature for a basis for standard or uniform procedure disclosed no exact one which could be recommended. The procedures described for the examination of "mineral water" are not applicable directly. Certain modifications which our experience has introduced are recorded here. Not all of the procedures described have been exhaustively studied as yet. The purpose of this paper is to make a beginning with the hope that others, who have had experience in this work, will contribute their experiences, or will criticize these procedures. In this way a procedure may be developed which may be accepted as standard. The object is to develop a method which will meet the needs of the manufacturing chemist rather than a method of exhaustive analysis. Brevity and speed of manipulation, with reasonable accuracy, are, therefore, the requirements.

ANALYTICAL PROCEDURES

SAMPLE—The sample when pumped from the earth will generally be clear, but on standing it becomes turbid due to the separation of a brown precipitate. This precipitate is mainly iron, but may contain silica and alumina. It is probably caused by oxidation and hydrolysis of ferrous bicarbonate. Generally by the time the sample will have reached the chemist the iron will have separated. The scheme of agitation to suspend the deposit uniformly through the

liquid before taking a part for analysis is inaccurate, as experiments have shown. Furthermore, the specific gravity is changed and this will affect the entire percentage composition. Consideration of this point has led us to conclude that the best procedure would be to collect a sample of about one liter, allow it to oxidize and settle completely, determine the amount of deposit, and then make analyses on the filtered sample. The analysis would not be exactly that of the original brine, but the difference will be very slight, and, since this procedure gives more nearly the thing that the manufacturer wants, it is best to proceed in this manner.

DEPOSIT ON STANDING (AERATION)—The sample of about one liter, which will usually contain some deposit, is allowed to stand, with occasional shaking, and removing of the stopper, for two or three days, or until deposition is complete and the precipitate settles well. The height of the liquid is carefully marked on the outside of the bottle, and the entire sample is then filtered, rejecting the first 100 cc. The precipitate is well washed, ashed and ignited to constant weight. The bottle is dried and the amount of water which it contained to the mark is determined. With these data the grams per liter are calculated, using the specific gravity of the filtered sample, and the result recorded as "*Deposit on Aeration.*" The errors will not be large if percentages be calculated, using this figure. Since in the industries all natural brines are exposed to air and allowed to settle before they are further treated, this value is just what is wanted by the manufacturer. Further examination of the precipitate is not necessary. It is a question whether or not it would be fair to assume the precipitate to be iron oxide (Fe_2O_3) and calculate it to, and report it as, ferrous bicarbonate.

SPECIFIC GRAVITY—The specific gravity is obtained by the Westphal balance, and is taken at 15° C., although perhaps it would be better to use 20° C., since this is more nearly the average temperature. The specific gravity of the fresh brine will be different from that of the sample through which the precipitate is suspended, and this in turn will be different from the filtered sample. On one brine, for example, the specific gravity of the filtered sample was 1.2307, while that of the sample in which the precipitate was suspended was 1.2342. If the chemist could take the specific gravity of the clear brine as soon as pumped

from the well it would no doubt be best, from the point of view of the original brine but this will generally be impractical. Even if the specific gravity could be obtained on the fresh brine there would be some volume change after the precipitate settled and a small error would be introduced when taking a filtered sample for later analyses. For these reasons, and also because the manufacturer is interested in the *settled* brine, it is believed that the best procedure is to use the filtered, aerated brine, and to determine the specific gravity with a Westphal balance at 15° C(?). This value is used in calculating percentages.

TOTAL SOLIDS—Many chemists omit this determination because of its questionable accuracy, but its value in calculating total water content for "evaporation fuel" comparisons makes it important. Brines rich in $CaCl_2$ require a rather high temperature, above 160° C., to expel the water completely. At this temperature the magnesium and calcium salts lose a part of their acid constituents, and a wide range of values will be obtained, depending on the temperature and duration of heating. The total solids can be calculated from the complete analysis, but this value should be checked by the total solids as obtained by evaporation. This point is being studied in this laboratory at the present time, and it is hoped that by a suitable arrangement the volatilized acids may be collected, titrated and then be added to the residual weight of the total solids. It may be that a weighed excess of some base may be added to retain the acid which is otherwise volatilized. The constituents likely to volatilize are chlorine, bromine, iodine (slight), sulfur trioxide and carbon dioxide (slight). The total solids are determined in the filtered sample, using 25-cc. portions and should be reported as *Total Solids by Evaporation*. This gives the manufacturer a basis for a reasonable estimation of the water to be evaporated in working the brine.

SILICA—A 25-cc. portion of the filtered brine is acidulated with 5 cc. of concentrated hydrochloric acid and is evaporated to dryness. It is then dried at 120° C., or higher if necessary, for an hour. Five cc. of hydrochloric acid are then added, the vessel is warmed, 20 cc. of water are added, and, after warming, the whole is filtered and washed free from chlorides. The filtrate is evaporated and treated as just described, and the operation is repeated on the second filtrate. The combined precipitates are ignited in a

platinum crucible, and weighed. The residue is treated with sulfuric and hydrofluoric acids. The loss in weight is reported as *silica*, and the residue is added to the iron and alumina.

IRON AND ALUMINUM—The filtrate and washing, which should contain 5 cc. of concentrated hydrochloric acid, are treated with a few drops of nitric acid, boiled a few minutes, and then made alkaline with ammonia. It is then boiled until all the ammonia is expelled, and after standing, is filtered, washed and ignited in the crucible from which the silica was expelled. The residue is reported as *Iron and Aluminum Oxides*. A separation of the iron and aluminum is not necessary. The results should be reported separately from the iron which separated on aeration. It should be remembered that the iron, aluminum and silica are not in solution as oxides, but as salts. For this reason there will be a slight difference between the total solids on evaporation and the calculated total solids.

Much time is saved if the iron, alumina and silica are all precipitated together, with ammonia. The amount of silica remaining in solution is very small. These constituents have no commercial value, and need not be reported separately. It should be remembered in this latter case that ammonium chloride must be added.

CALCIUM—The filtrate from the iron and aluminum is diluted to 250 cc. and 25 cc. are taken; this is diluted to 150 cc., heated to boiling and a hot 10 per cent solution of ammonium oxalate is added in excess. After standing for some time (15 minutes), it is filtered and washed with hot water. The precipitate is dissolved in warm dilute hydrochloric acid, a little ammonium oxalate solution added, and ammonia then slowly added to complete the precipitation. The precipitate is filtered out, after standing one-half hour, and is ignited to the oxide and weighed, or is dissolved in dilute sulfuric acid and titrated with permanganate. Our experience seemed to show that it was not necessary to allow the precipitate to stand 12 hours as is recommended in some of the books on water analysis. The calcium should be reported as sulfate and chloride.

MAGNESIUM—The combined filtrates and washings from the calcium are acidified with hydrochloric acid, a large excess of sodium hydrogen phosphate is added, and then ammonium hydroxide with constant stirring

until the liquid smells of ammonia. Ten cc. of strong ammonia are added in excess and the whole is allowed to stand 12 hours. The precipitate is filtered out, washed with dilute ammonia and redissolved in hydrochloric acid (1 : 5). The volume is made up to 75 cc., a little sodium hydrogen phosphate added, and then ammonia, drop by drop, with constant stirring until the solution smells strongly. After 4 hours the magnesium is filtered out on an alundum or Gooch crucible, washed with 2 per cent ammonia water, dried and ignited to $Mg_2P_2O_7$. If an alundum crucible is used it should be heated within a glazed crucible. The magnesium should be calculated to the bromide and chloride.

The above procedure gave very good results. In the usual procedure the filtrate from calcium is evaporated to dryness, and the ammonium salts are volatilized. This requires great care, and much time, and did not give any better results than the procedure described. The reprecipitation must be carried out, even on very small amounts. There seems to be good authority, however, for the evaporation and ignition which we have omitted, and the point should be investigated further.[1]

BARIUM AND STRONTIUM—If no sulfates are present, barium and strontium must be looked for. Indeed a case is on record where barium, lead and sulfuric acid were present simultaneously in a natural mineral water.[2] From work in progress in this laboratory it seems, however, that in the case of brines, where very little CO_2 is present, that sulfates preclude the presence of barium or strontium. Barium oxalate is sparingly soluble, and a strontium oxalate is insoluble in water. When these metals are present they will be partially precipitated along with the calcium. This point seems to have been overlooked hitherto. In cases where the barium and strontium amount to 0.2 per cent the error introduced cannot be neglected. The magnesium results may also be affected. It may be possible to precipitate the barium and strontium with ammonium sulfate before precipitating the calcium, but no work has been done on this phase. The fact that the barium is not completely precipitated by

[1] In the discussion of this paper in the Industrial Division it was suggested that the speedier method for magnesium, used in Low's "Technical Methods of Ore Analysis," p. 159, might be of service here but we have not yet investigated this method, or the method of precipitation with sodium hydroxide sometimes used on traces of magnesium.

[2] Carles, *Ann. chim. anal.*, **1902**, 91.

ammonium oxalate makes it impossible to apply a correction to the calcium precipitate. The determination of the barium and strontium in the calcium precipitate is too time-consuming to be practical for the ordinary technical analysis. When the barium and strontium content is small the error can be ignored. The procedure used was identical with the one described in the *Department of Agriculturel Bull.*, **91**, "Mineral Waters of the United States," by J. K. Haywood and B. H. Smith; a simpler method has not yet been found.

AMMONIA—Traces of ammonia have been reported in some brines, but the amount is generally so small as to be of no commercial importance. It may be, however, that its significance is greater than we now know, especially in brines for electrolysis. The suggestion has been made by cell operators that nitrogen chloride may be connected with the explosions which occur from time to time in electrolytic chlorine apparatus. If this should prove true the determination of ammonia will be important.

SULFURIC ACID, SODIUM AND POTASSIUM—Fifty cc. of the filtrate from the iron and alumina are diluted to 100 cc. and treated, while boiling hot, with 10 per cent $BaCl_2$ solution, adding it slowly, and with constant stirring. The $BaSO_4$ is filtered off, the paper burned off in a porcelain crucible, and the precipitate dissolved in a few cc. of warm, concentrated sulfuric acid. The solution is now carefully poured into 250 cc. of water, and, after standing some time, is filtered, washed and ignited. It should be reported as calcium sulfate. This method of freeing the $BaSO_4$ from iron and other absorbed matter is very effective. It is essentially that taught for decades at the John Harrison Laboratory, University of Pennsylvania, Philadelphia.

The filtrate from the sulfuric acid is used for sodium and potassium. From this point, the procedure we have been using is the *same* as described in "Mineral Waters in the United States," *Department of Agriculture Bull.*, **91**, *Loc. cit.* It is difficult, however, to determine small amounts of potassium in the presence of large amounts of sodium chloride, and it is believed that some procedure[1] should be used which will precipitate most of the sodium first.

CHLORINE—The brine should be tested with phenol-

[1] Professor C. W. Foulk, of the Division of Analytical Chemistry of the Ohio State University laboratory, is now investigating this matter.

phthalein. It will usually be neutral, but if it is not, it should be made so with $NaHSO_4$ solution. 10 cc. of the filtered sample are diluted to a liter and 10 cc. used for titration. This is diluted to 200 cc., 2 cc. of K_2CrO_4 solution are added and the mixture is titrated to the end-point. Na_2CrO_4 would probably be a satisfactory indicator here but we have not yet proved this to be true. Take an amount of standard sodium chloride solution equivalent to the amount of silver nitrate used, dilute to 200 cc. and titrate as before. The difference represents the amount necessary to affect the indicator and should be subtracted. This procedure is accurate enough since *the chlorine is used only as a check on the analytical work.* The bromine value must be deducted.

BROMINE—The colorimetric procedure, as given for ordinary waters, is not usable with brines. Experiments showed that after repeated extraction with 90 per cent alcohol the residue still contained bromine. The distillation methods are time-consuming and not very easily manipulated. For these reasons a colorimetric method was developed.

Procedure—100 cc. of the brine are made alkaline with Na_2CO_3 and are evaporated to dryness. It is then taken up in water and filtered into a 250-cc. flask. It is made distinctly acid with H_2SO_4 and is diluted to the mark: 25 cc. are pipetted into a 50-cc. Nessler tube and chlorine is added until the maximum color has developed: 10 cc. of carbon tetrachloride are then added, and the mixture is shaken and compared with a set of standards made up from NaBr solution in the same way. By this rough check the approximate amount of bromine will be discovered, and a set of standard solutions are then prepared which are very close above and below the unknown solution. Again 25 cc. are taken, chlorine water is added to a maximum color and the same amount is added to the standards; the sample is then shaken with 10 cc. of CCl_4 and poured into a wet filter; when the water has drained off the filter should be punctured and the liquid caught in a 25-cc. Nessler tube (this is best done in a darkened room but darkness is not essential). If a sample does not exactly match the standard the colors can be compared by diluting with CCl_4; or since the operation is so simple, a new set of standards can be made up, and then a new determination made. If a test shows that all bromine was not extracted by

10 cc. of CCl_4 a second extraction should be made. This is generally not necessary.

Traces of iodine which are present in most brines will not interfere. The iodine need not be reported.

It is difficult to appreciate the unreliability of published statements regarding the occurrence of bromine. For instance, although the State of Michigan reports, and the most reliable information states, that Midland, Mich., brine contains 0.1 per cent of bromine, yet the most exhaustive German work on bromine[1] states on page 3 that the brine from Midland, Ohio, *sic.*, contains 4.18 per cent magnesium bromide which is equivalent to 3.63 per cent bromine, or 36 times stronger than those who operate on it claim it to be.

REPORTING RESULTS

The results should be reported in such a manner as to give the manufacturer the thing which he wants. The reporting of the constituents as ions, while strictly scientific, is of no value to the manufacturer. All of the sodium and potassium should be calculated to chloride. Since the $CaSO_4$ separates on the copper tubes in the evaporators the H_2SO_4 should be reported as calcium sulfate. The bromine should be calculated as magnesium bromide, since it has long been so considered in the trade; but bromine as free bromine should also be reported. The residual calcium and all the magnesium are calculated to chlorides since they go on the market as such. Strontium and barium should be given as chlorides. The silicon should be reported as the oxide since the form in which it is combined is not known. Iron and aluminum are reported together as oxides since their separation is too time-consuming. The residue which separates on standing should also be given. Results are preferably reported in percentages though some manufacturers are accustomed to *grams per liter*. The specific gravity and temperature should always be reported; for this reason also, a standard temperature should be used so that results would be really comparable.

When the positive and negative ions are calculated to compounds they should nearly satisfy each other. It should be borne in mind, however, that the iron, aluminum and silicon are given as oxides, and not as salts, in which form they usually occur in the brine.

[1] "Monographien ü. angewandte Electrochemie. Über d. elektrolytische Gewinnung von Brom," by Max Schlötter.

There may also be small amounts of CO_2 and iodine which are not included. If, however, the check is not reasonably close, it indicates an error, or else some undetermined constituent is present.

As an illustration of the extremes in composition which the analyst must expect to meet, two examples from Ohio brines will serve.

BRINE SOURCE:	Eastern Ohio Coal Mine	Southern Ohio Driven Well
Specific gravity	1.034	1.180
Baumé equivalent	4.8°	22.2°
Sodium chloride	3.26 per cent	12.08 per cent
Magnesium bromide	0.007	0.124
Bromine	0.006	0.107
Calcium chloride	1.63	10.81
Magnesium chloride	0.05	2.61
Calcium sulfate	0.001	0.03
Iron and aluminum oxides	0.21	0.04
Silica	0.12	0.002
Residue on evaporation	5.23	29.00

While this work considers primarily the commercial natural brines, the same procedure will doubtless apply to the analysis of artificial brines, such as used in soda ash manufacture and in electrolytic cells, although the amounts of calcium and magnesium will be much less in these solutions.

LABORATORY OF INDUSTRIAL CHEMISTRY
OHIO STATE UNIVERSITY, COLUMBUS

College of Engineering.

Bulletins 1-17.

No. 1. Paving Brick — Orton.
No. 2. White Ware Body Mixtures — Purdy + Potts.
No. 3. Rattler test for paving brick — Blair + Orton
No. 4. Superheated Steam — Hitchcock.
No. 5. Sand blasting machine — Magruder.
No. 6. Bismuthate Method for Manganese and a new method for Vanadium — Demorest.
No. 7. Road building materials of Coshocton County, Ohio — Eno.
No. 8. Stresses in tall buildings — Melick.
No. 9 Electrolytic Disposition of Sewage — Caldwell.
No. 10. Effect of Lime Sulphur Spray Manufacturing on the eyesight — Withr
No. 11. The Wood Turpentine Industry — French + Withrow.
No. 12. The Ohio Coal Supply — Ray.
No. 13. The Hardwood Distillation Industry in America — Frenc Withro
No. 14. Laps and lapping — Knight + Case.
No. 15. The Ohio Water Problem — Sherman.
No. 16. Congress of Human Engineering.
No. 17. The Chemical Examination of Natural Brines — Sweeney Withrow.

Toledo
Ele. 573
LAKE ERIE
Conneaut
Ashtabula
Fairport
Painesville
Montpelier
WILLIAMS
FULTON
Wauseon
Bryan
LUCAS
CANAL
MAUMEE RIVER
Port Clinton
OTTAWA
Sandusky
Lorain
Cleveland
Chardon
GEAUGA
ASHTABULA
GRAND RIVER
CHAGRIN
Napoleon
HENRY
DEFIANCE
WOOD
PORTAGE R.
Bowling Green
SANDUSKY
Fremont
Clyde
ERIE
Bellevue
HURON R.
Elyria
LORAIN
Oberlin
CUYAHOGA
Berea
CUYAHOGA R.
TRUMBULL
Defiance
Warren
Niles
Paulding
PAULDING
Fostoria
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HURON
VERMILLION RIVER
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MEDINA
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PORTAGE
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Cap.1.4
BLANCHARD
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Findlay
SENECA
Akron
MAHONING
PUTNAM
HANCOCK
Carey
A
Cap.23
DIVIDE BETWEEN LAKE ERIE AND OHIO RIVER
Barberton
Cap 0.33
Alliance
Salem
Leetonia
Van Wert
Delphos
VAN WERT
WYANDOT
CRAWFORD
Shelby
Ashland
ASHLAND
Orrville
STARK
COLUMBIANA
ALLEN
AUGLAIZE R.
OTTAWA R.
Upper Sandusky
Bucyrus
RICHLAND
Wooster
WAYNE
Massillon
Canton
Lima
B
Cap.9
Galion
Mansfield
ROCKY FORK
KILLBUCK
ST. MARYS R.
HARDIN
Kenton
Marion
CANAL
CARROLL
East Liverpool
Celina
Cap.3
AUGLAIZE
Wapakoneta
Millersburg
HOLMES
Canal Dover
Carrollton
WABASH R.
MERCER
St. Marys
MARION
MORROW
New Philadelphia
Toronto
JEFFERSON
Steubenville
Cap.1.5
LOGAN
C
Cap.1.5
SCIOTO
D
Cap.2
KNOX
Mt. Vernon
OWL CR.
MOHICAN R.
WALHONDING
TUSCARAWAS
OHIO
Uhrichsville and Dennison
Cap.0.5
SHELBY
Cap.2
Bellefontaine
UNION
Delaware
DELAWARE
COSHOCTON
Coshocton
TUSCARAWAS
Port Washington
HARRISON
Cadiz
Sidney
Cap.3.75
Marysville
OLENTANGY
WILLS
DARKE
Piqua
CHAMPAIGN
Urbana
E
Cap.0.25
RIVER
LICKING
Dresden
GUERNSEY
Greenville
MIAMI
Troy
Cap.10
CLARKE
Newark
LICKING R.
MUSKINGUM
Cambridge
Barnesville
BELMONT
Bellaire
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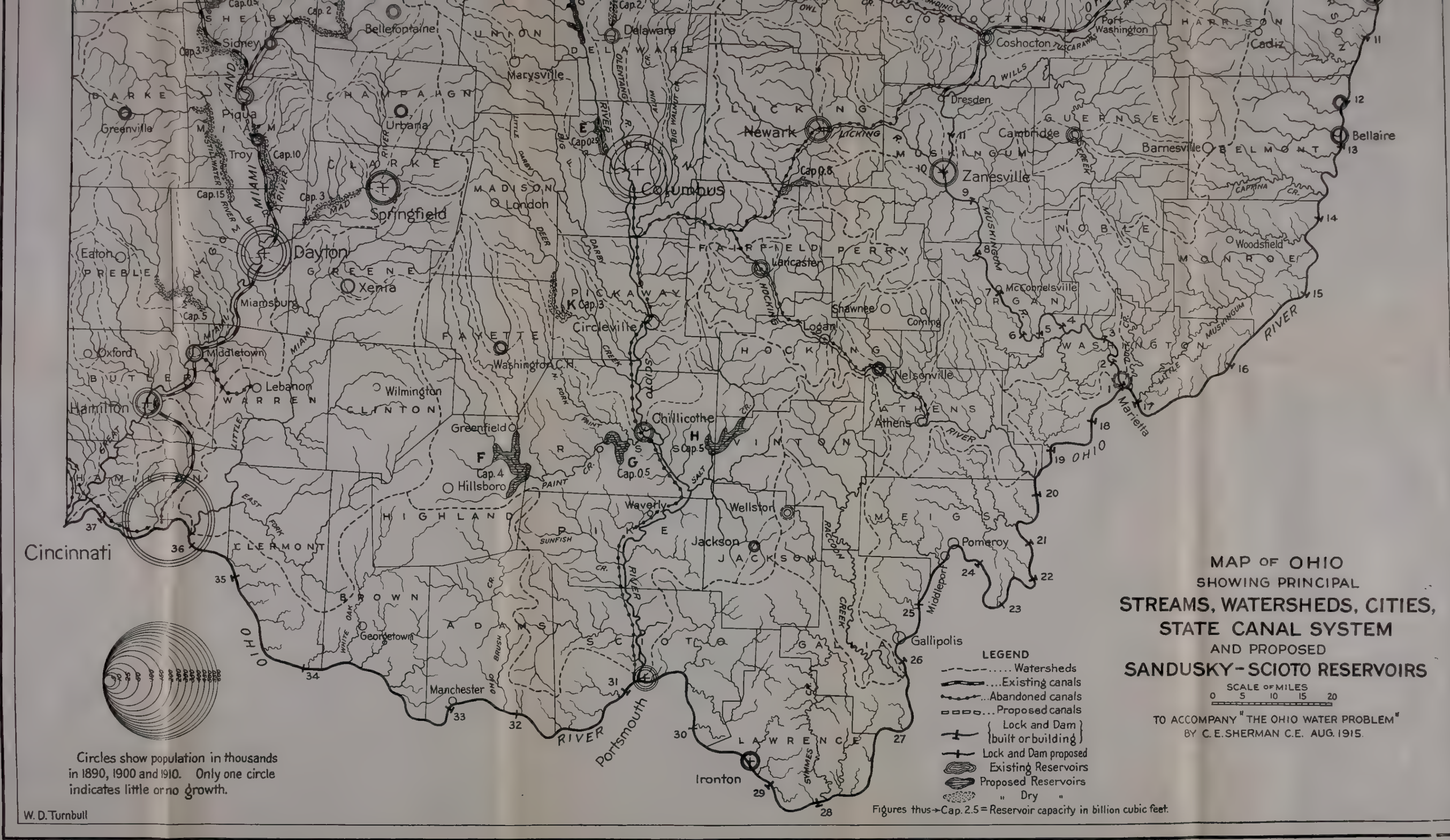
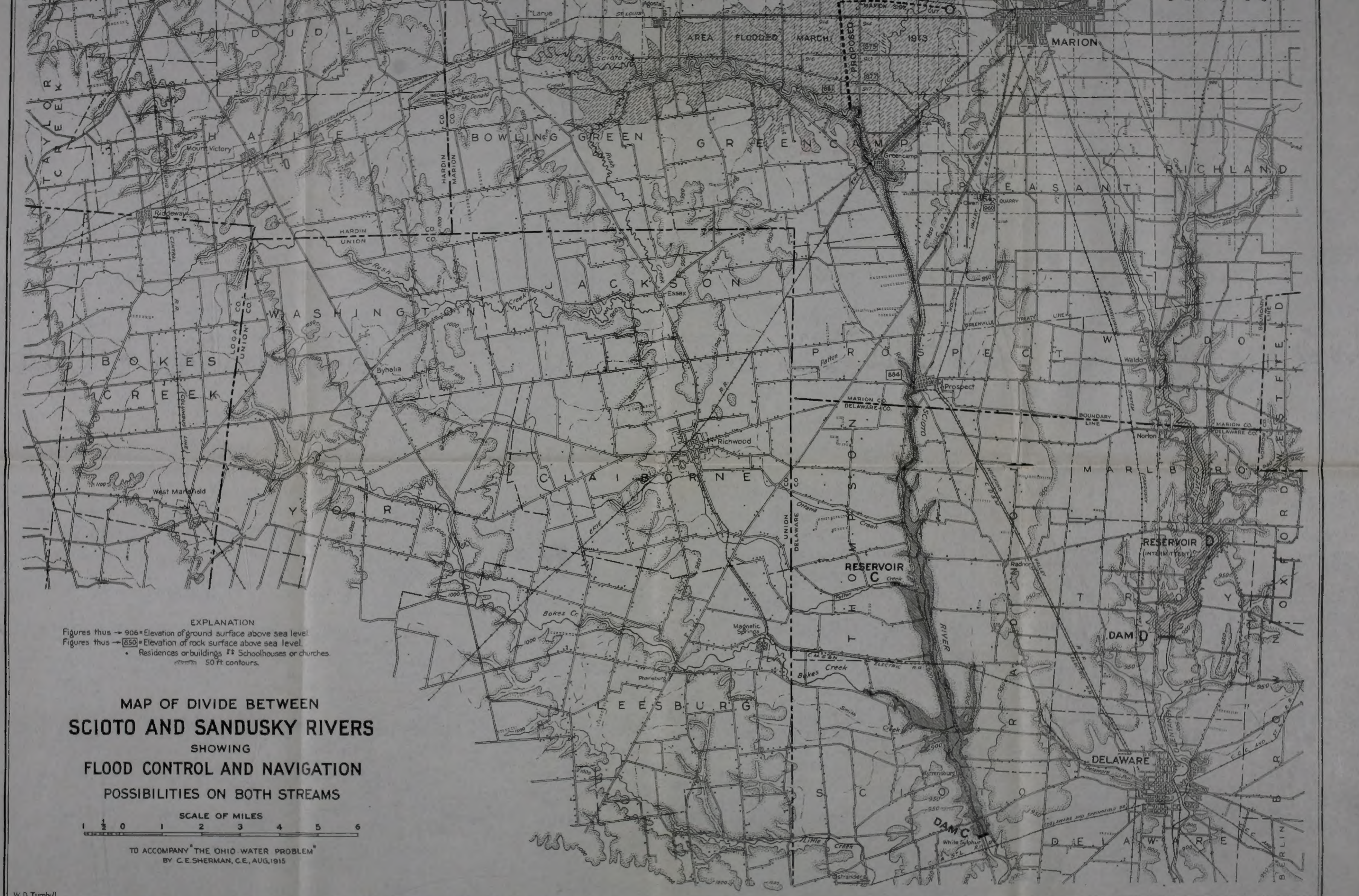

MAP OF OHIO
SHOWING PRINCIPAL
STREAMS, WATERSHEDS, CITIES,
STATE CANAL SYSTEM
AND PROPOSED
SANDUSKY-SCIOTO RESERVOIRS
SCALE OF MILES
0 5 10 15 20
TO ACCOMPANY "THE OHIO WATER PROBLEM"
BY C. E. SHERMAN C.E. AUG. 1915.
LEGEND
..... Watersheds
.... Existing canals
... Abandoned canals
... Proposed canals
Lock and Dam {built or building}
Lock and Dam proposed
Existing Reservoirs
Proposed Reservoirs
" Dry "
Figures thus → Cap. 2.5 = Reservoir capacity in billion cubic feet.
Circles show population in thousands in 1890, 1900 and 1910. Only one circle indicates little or no growth.
W. D. Turnbull

RESERVOIR A (JUST ABOVE LIMITS OF MAP)
DELAWARE
RICHLAND
SALEM
UPPER SANDUSKY
EDEN
HOLMES
CRANE
Kirby
Forest
Nevada
JACKSON
MIFFLIN
BLANCHARD
Patterson
JACKSON
McVitty
PITT
ANTRIM
BUCYRUS
DAM B
PROPOSED SUMMIT LEVEL RESERVOIR B
Harpster
Wyandot
MORAINE
Grant
MARSEILLES
Marseilles
DALLAS
WYANDOT CO
MARION CO
Morral
PLEASANT
POSSIBLE RESERVOIR b
GOSHEN
GRAND
SALT ROCK
GRAND PRAIRIE
SCOTT
KENTON
SUMMIT LEVEL CUT
Meeker
DIVIDE
Hepburn
MONTGOMERY
BETWEEN
BIG ISLAND
Big Island
MARION
CLARIDON
BUCK
DUDLEY
Larue
MARION SIDE CUT
AREA FLOODED MARCH 1913
PROPOSED
MARION
TAYLOR CREEK
HALE
Mount Victory
HARDIN CO
MARION CO
BOWLING GREEN
GREEN CAMP
Green Camp
RICHLAND
PLEASANT
Ridgeway
HARDIN CO
UNION CO



MAP OF DIVIDE BETWEEN
SCIOTO AND SANDUSKY RIVERS
SHOWING
FLOOD CONTROL AND NAVIGATION
POSSIBILITIES ON BOTH STREAMS

TO ACCOMPANY "THE OHIO WATER PROBLEM"
BY C. E. SHERMAN, C.E., AUG. 1915


TRANSPORTATION ROUTES OF THE WORLD
COMPILED FROM MAPS PUBLISHED BY VARIOUS BUREAUS OF THE UNITED STATES GOVERNMENT AND BY THE NATIONAL GEOGRAPHIC SOCIETY.
Railroad Routes
Steamship Routes
Caravan Routes
Ocean distances are in sea miles or nautical miles.
LENGTH OF A KNOT.
A sea mile or nautical mile or knot in U.S. = 6080.27 feet.
Same in France, Germany and Austria = 6076.23 " .
A nautical mile or admiralty knot in Eng. = 6080.00 " .
" geographical mi. = 1' of longtitude at equator = 6087.15 " .
" statute mile . . . . = 5280.00 " .
(From U.S. Hydrographer's Chart Sept. 1909.)
TO ACCOMPANY "THE OHIO WATER PROBLEM"
BY C.E. SHERMAN C.E. AUG. 1915
W. D. Turnbull
INTERNATIONAL DATE LINE
Nome
Cordova
Juneau
Seward
Sitka
Prince Rupert
Unalaska
Petropavlosk
Port Nelson
Victoria
San Francisco
New York
BERMUDA
Harbin
Vladivostok
Peking
Tientsin
Hankau
Shanghai
Nagasaki
Yokohama
Hong-kong
Manila
GUAM I.
WAKE I.
MIDWAY I.
HAWAIIAN IS.
Singapore
SAMOA IS.
SOCIETY IS.
Brisbane
Sydney
Fremantle
Albany
Adelaide
Melbourne
Wellington
Caracas
TRINIDAD IS.
Guayaquil
Para
Pernambuco
Bahia
Callao
Lima
Iquique
S. Paulo
Rio de Janeiro
Valparaiso
Montevideo
Buenos Ayres
Punta Arenas
Reykjavik
Hammerfest
Narvik
Archangel
St. Petersburg
Moscow
Omsk
L. Baikal
Irkutsk
Tangier
Algiers
MALTA
P. Said
Cairo
Aden
Bombay
Calcutta
Rangoon
Madras
Colombo
Freetown
Mombasa
ZANZIBAR
Cape Town
Port Natal
Port Elizabeth
Kobe
P. Arthur
N.Y. to London 3300
N.Y. to Bordeaux 3187
N.Y. to Gibraltar 3202
N.O. to London
N.O. to Liverpool
N.O. to Gibraltar 4466
Colon to London
Colon to Gibraltar 4252
London to Pernambuco 4130